CALCULATION OF INDIRECT LAND USE CHANGE (ILUC) VALUES FOR LOW CARBON FUEL STANDARD (LCFS) FUEL PATHWAYS

Interim Report

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Disclaimer

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Abstract

This interim report provides updated estimates of land use impacts of US corn ethanol, US soybean biodiesel, and Brazilian sugarcane ethanol production. In addition, it provides sensitivity analysis on the sensitivity of land cover changes with respect to changes in food demand induced by higher commodity prices due to biofuels. Sensitivity analysis also is conducted on the yield-price elasticity used to reflect the medium term changes in crop yield due to changes in crop price. In addition, sensitivity analyses were performed on the transformation elasticity of cropland among crops and on the endogenous productivity increase in cropland pasture.

Executive Summary

This document constitutes an interim report for California Air Resources Board (CARB) contract 10-408. The research under this contract provides revised indirect land use change (ILUC) estimates for US corn ethanol, US soy biodiesel, and Brazilian sugarcane ethanol. In addition, it covers four groups of sensitivity analyses:

- Sensitivity of land cover changes with respect to changes in the food demand induced by higher food prices due to biofuel production
- Sensitivity of land cover changes with respect to yield-to-price elasticity
- Sensitivity of land cover changes with respect to crop transformation elasticity
- Sensitivity of land cover changes with respect to endogenous productivity change for cropland pasture

Land use impacts of US corn ethanol

We model an increase in US corn ethanol production by 11.59 billion gallons per year (bg/y), which increases US corn ethanol from its 2004 level to 15 bg/y. Global cropland expands by 2,126,261 hectares (ha) resulting in 290,637 ha of forest land loss and 1,835,267 ha of pasture loss. As expected, the largest cropland expansion is observed in US (1,002,512 ha), followed by Sub Saharan Africa, EU27 and Canada. The largest forest land losses are observed in US, Canada, and EU. Pasture losses are widely distributed. Producing **1000 gallons of US corn ethanol requires 0.18 hectares of new cropland** of which 0.025 comes from forest land and 0.158 from pasture. If cropland pasture is included in the converted land base, then the number goes to 0.31 ha/1000 gal.

Land use impacts of US soybean biodiesel

We model an increase in US soybean biodiesel of 0.812 billion gallons per year (bg/y), which, holding the 2004 soy biodiesel share constant brings the total biodiesel level to one billion gallons. Global cropland expands by 143,189 ha resulting in reforestation by 2,179 ha and loss of 145,369 ha of pasture land. As expected, the largest cropland expansion is observed in the US (97,418 ha), followed by Brazil and South America, which are the main soybean producers across the world. The largest forest land losses are observed in US and Brazil. Producing biodiesel from soybean causes reforestation in many regions across the world because production of soybean biodiesel in the US increases exports of US soybean meals to other countries. This reduces the demand for domestic meal in other regions across the world which leads to reduction in the demand for cropland and reforestation in those regions. Producing **1000 gallons of US soybean biodiesel requires 0.18 hectares of new cropland** which mainly comes from pasture land with no significant change in forest area at the global scale. If cropland pasture is included in the converted land base, then the land requirement becomes 0.43 ha/1000 gal.

Land use impacts of Brazilian sugarcane ethanol

We model the increase of Brazilian sugarcane ethanol production with Brazilian production increasing 3 bg/y and exports to the US by 1 bg/y. Global cropland expands by 471,693 ha resulting in 96,897 ha of forest land loss and 374,589 ha of pasture loss. The largest cropland expansion is observed in Brazil (221,760 ha), followed by Sub Saharan Africa, EU27, and US. The largest forest land losses are observed in Brazil, EU27 and Canada. The largest pasture losses are observed in Brazil, US, and Sub Saharan Africa. **1000 gallons of Brazilian sugarcane ethanol requires 0.16 ha of cropland**, of which 0.03 comes from forest land and 0.13 from pasture. If cropland pasture is included in the converted land base, the requirement becomes 0.40 ha/1000 gal.

Sensitivity of land cover changes to food consumption changes

The results do not show large sensitivity of land cover change to the different assumptions on food consumption as shown in the table below. Of the three biofuels considered, US soy biodiesel is most sensitive to the assumption about changes in food demand in percentage terms, and US corn ethanol is least sensitive. However, the absolute change for soy biodiesel for the extreme case is only 0.05 million ha.

Global Cropland Needed by Food Consumption Case (million ha)

Case	Food consumption adjusts in response to changing prices	Food consumption is fixed in developing countries	% change from base	Food consumption is fixed globally	% change from base
US Corn ethanol	2.13	2.34	10%	2.5	17%
US biodiesel	0.14	0.17	21%	0.19	36%
Brazilian sugarcane	0.47	0.54	15%	0.57	21%

Sensitivity analysis on the yield-to-price elasticity

There is no yield change in this version of the GTAP model other than that induced by a change in the commodity price. The logic is that a higher commodity price would in the medium term bring about higher yields. There are several empirical studies which estimated the magnitude of this elasticity, but there is no commonly agreed value among the profession. In the base cases in this report and in most previous work, a value of 0.25 is assigned to this elasticity. We were asked to do sensitivity analysis with lower values of 0.10 and 0.05. The following table summarizes the results of the sensitivity analysis:

Global Cropland Needed by Yield Price Elasticity Case (million ha)

Case	Yield price elasticity		% change from base case	Yield price elasticity	% change from base case
	0.25	0.10		0.05	
US Corn ethanol	2.13	2.85	34	3.21	51
US biodiesel	0.14	0.20	40	0.23	60
Brazilian sugarcane	0.47	0.60	28	0.67	42

The results in all cases are sensitive to the value of the price-yield elasticity. Of the three sugarcane is least sensitive, and soybean is the most sensitive.

<u>Sensitivity on cropland transformation elasticity and cropland pasture endogenous technical change elasticity</u>

The results are not very sensitive either to the cropland transformation elasticity or the endogenous cropland yield elasticity assumptions.

<u>Conclusions</u>

The induced land cover changes due to the US corn ethanol, US soybean biodiesel, and Brazilian sugarcane are about 0.18, 0.18, and 0.16 ha/ 1000 gal., respectively. The corn ethanol results are in line with the Purdue 2010 results. These results are significantly lower than the 2009 CARB results of 0.29, 0.63, and 0.55 ha for US corn ethanol, US soy biodiesel, and Brazilian sugarcane ethanol. If cropland pasture is included in the converted land base, the land needed becomes 0.31, 0.43, and 0.40 ha/1000 gal. for corn ethanol, soy biodiesel, and sugarcane ethanol, respectively.

The food consumption sensitivity tests indicate that the land cover change is somewhat sensitive to changes in the food consumption assumption. However, the restrictions on food consumption in the alternative cases are pretty severe, and the magnitude of changes is relatively small.

The results are quite sensitive to changes in the yield-price elasticity. Unfortunately we do not have a good empirical base for this parameter, so sensitivity analysis is appropriate.

The results are not very sensitive to the assumptions on cropland transformation elasticity or cropland pasture endogenous yield elasticity.

INTERIM REPORT TO THE CALIFORNIA AIR RESOURCES BOARD

Introduction

This document constitutes an interim report for California Air Resources Board (CARB) contract 10-408. The research under this contract provides revised indirect land use change (ILUC) estimates for several important biofuels. This report covers US corn ethanol, US soy biodiesel, and Brazilian sugarcane ethanol. In addition, it covers two groups of sensitivity analyses:

- Sensitivity of land cover changes with respect to changes in the food demand induced by higher food prices due to biofuel production – Two previous studies [1, 2] examined the impacts of freezing food consumption on the induced land use changes due to biofuel production, and both concluded that producing biofuels slightly reduces food consumption and that freezing food consumption increases induced land use changes moderately. Most GTAP analysis done to date used the standard change in food consumption resulting from an increase in food commodity prices. It is likely that government policy interventions to hold food prices constant are not captured in the model. However, we do not know how important that would be. To assess the sensitivity of the land use changes induced by biofuel production with respect to reduction in food consumption we perform the following three sets of experiments: 1) Standard GTAP responses; 2) Food consumption frozen in developing countries and standard GTAP response elsewhere; and 3) Food consumption frozen everywhere.
- Sensitivity of land cover changes with respect to yield-to-price elasticity – In the past, all the work using GTAP has used a price-yield elasticity of 0.25, meaning that a 10% increase in price leads to a 2.5% increase in yield for a given crop, everything else being equal. The CARB Expert Working Group suggested sensitivity analysis on this parameter, and that is included in this report using alternative values of 0.1 and 0.05 provided by CARB.
- Sensitivity analysis on land cover changes with respect to crop land transformation elasticity – Historically, we had used a cropland transformation elasticity of -0.5. However, evidence in the past decade suggested that land was moving among crops with much greater facility than in the past, so based on this evidence we have increased the base value of the parameter to -0.75. However, CARB requested that results also be reported with the old value of -0.5.
- Sensitivity analysis on land cover changes with respect to endogenous productivity increase for cropland pasture – The newer versions of the GTAP-BIO model have incorporated an endogenous productivity increase in cropland pasture based on the endogenous increase in cropland pasture rent as more and more cropland pasture is used for energy crops. In this analysis, we used values of 0.4 and 0.2 for the US and Brazil, the only countries with cropland pasture in the database. CARB requested that values of zero also be simulated.

In addition to these sensitivity analyses included in this report, there are several other modeling and data sensitivity analyses that will be done over the next two years. These are described briefly in this section to clarify what is and what is not included in the analysis contained in this report.

The first (in no particular order) longer term analysis will be sensitivity analysis with respect to the Armington structure used in GTAP. The two basic structures for modeling international trade are Armington and Heckscher-Ohlin. The Heckscher-Ohlin structure assumes instant adjustment in trade patterns and quantities to even small changes in price. It is akin to a perfect competition among imports of a commodity from different regions assumption. The Armington structure assumes trade patterns are sticky, and it takes time and larger price changes to disrupt historical trade patterns. It assumes internationally traded commodities classified under one category are differentiated by country of origin. Most, but not all of the literature supports the Armington structure in the short-run. However, when the impacts of the shock or policy change play out over several decades (e.g., climate change), many have questioned the Armington structure. Biofuels may be somewhere in between. Thus, it certainly seems appropriate to test the sensitivity of the Armington structure and trade elasticities.

The analysis in this report will take advantage of new emission factors to be provided by CARB. However, beyond that substitution of one set of factors for the ones previously used, CARB is also interested in exploring emission factors and soil carbon changes due to crop switching. To date, all the GTAP analysis has assumed that crop switching (e.g., soybeans to corn) does not cause any change in GHG emissions. Using data to be provided by CARB, we will test new factors in the longer term analysis.

In a similar vein, we will also evaluate potential soil carbon changes due to use of cellulosic feedstocks for biofuels in future experiments. It is likely that removal of corn stover will reduce soil carbon, and cultivation of dedicated energy crops such as miscanthus and switchgrass may increase soil carbon. We have ongoing research at Purdue funded by others that will provide input into this analysis. In addition, CARB may provide data to be used.

One area of uncertainty is the yield of new land brought into crop production compared to the existing cropland. At present we use data from the Terrestrial Ecosystems Model to provide information on the expected productivity of new land brought into cultivation [3]. CARB is interested in exploring other approaches to estimating productivity of new land. CARB will provide Purdue suggestions and, if needed, data to do sensitivity analysis in this area. We will also examine the sensitivity of the land cover changes with respect to assumptions regarding cropland pasture yield.

Future changes in technology (especially yields) and in crop demand are important long run determinants of the land use impacts of biofuels. We will explore using a dynamic version of GTAP or other approaches to make explicit assumptions of future yield and demand growth.

Estimation of induced land use changes due to biofuels is uncertain. GTAP and other models used for this purpose contain thousands of parameters and data elements as well as the assumed model structure, all of which cannot be known with certainty. We can, however, conduct systematic sensitivity analysis on key parameters. In consultation with CARB staff, we will select a set of key parameters to test.

The next section of this report, the methods section, describes the model and data modifications that were undertaken to create the model version used for this analysis. Following that, the results section provides the results for the revised corn ethanol, sugarcane ethanol, and soy biodiesel simulations. The results section also includes the sensitivity analysis on the price-yield elasticity and the food consumption change due to higher commodity prices. The final section, summary and conclusions, provides the major findings of this analysis.

Methods

This section is divided into two parts: model modifications and data modifications. Of course, the two parts are closely related. Many of the model modifications and data modifications have been reported elsewhere [3, 4], so they will be summarized here.

Model modifications

The following model modifications are summarized in this section:

- Updated energy elasticities,
- Improved treatment of DDGS and oilseed meals and oils,
  - Separation of soybean from other oilseeds,
  - Separation of soybean oil from other vegetable oils and fats,
- Separation of soybean biodiesel from other types of biodiesel,
- Modified model structure for livestock sector,
- Revised land conversion factor for new cropland,
- Incorporate cropland pasture for US and Brazil and CRP for US,
- Endogenous yield adjustment for cropland pasture,
- Greater flexibility in cropland switching in US.

Updated energy elasticities

CGE models have garnered much use recently, particularly in applications related to energy, climate change, and biofuels. However, with few exceptions, these models have not been validated against historical data. This research performed such a validation exercise using the widely used/adapted GTAP-E model of energy and climate policy. A careful investigation into the ability of this model to replicate historical price volatility, given medium run stochastic shocks to supply and demand in the world petroleum market, revealed that both demand and supply specifications in the previous model were too price-elastic. Further investigation suggested that the elasticities of substitution between petroleum and other fuels were too high, as was the consumer demand elasticity for petroleum products in many countries [5]. In addition, supply response in the petroleum sector appeared to be too large. After revising the model parameters to bring them in line with estimates from the literature, we obtained a model which is capable of more closely replicating the second moments of the regional petroleum price distributions. These revised parameter specifications are now included in the model version we use.

Improved treatment of DDGS and oilseed meals and oils

A major attempt has been made to introduce production, consumption, and trade of biofuel byproducts into the GTAP modeling framework. Taheripour et al. [1] and Taheripour, Hertel, and Tyner [6, 7] represent the latest modifications in this area. These papers extend the original GTAP-BIO database [8] and its modeling framework in several directions to properly trace the links among biofuel, vegetable oil, food, feed, and livestock industries [2]. In this report we adopt these modifications and make further necessary changes to achieve the targets of this project. In particular in this work the US uses corn and EU uses wheat in their ethanol production processes. The ethanol industry in in this work produces ethanol and distillers dried grains with solubles (DDGS). We divided the traditional oilseed industry of GTAP (*osd*) into two new distinct sectors of *Soybeans* and *Oth_Oilseeds*. Following this modification we also divided the standard vegetable oil industry (*vol*) of GTAP into two new industries of *Vol_Soy* and *Vol_Oth.* The former industry crushes soybean and produces two commodities of soybean oil and soybean meal and the latter industry produces other types of vegetable oils and fats in conjunction with non-soy meals.

Separation of soybean from other oilseeds

In this work we divided the standard GTAP oil seed industry (*osd*) into two industries of *Soybean* and *Other-Oilseeds*. These two crop industries compete in land, capital, labor, and intermediate market and sell their products to other industries (mainly vegetable oil, food and feed industries) and households. Both of these industries are involved in trade as well. In the section of data modification we will explain introducing these commodities into the database.

Separation of soybean oil from other vegetable oils and fats

We also divided the traditional vegetable oil industry of GTAP into two new distinct industries of: *Soy_Vol* and *Oth_Vol*. The first industry obtains its main input from the soybean industry and crushes this seed to produce soybean oil and soybean meals. The second industry uses other types of oilseeds and fats to produce other types of vegetable oils, fats, and meals. Both industries are active agents in the resource (except for land) and commodity markets and sell their products to domestic and international markets. In the section of data modification we will explain introducing these commodities into the database with details.

Separation of soybean biodiesel from other types of biodiesel

In the model designed for this work we have introduced two biodiesel industries of: *Biod_Soy* and *Biod_Oth*. The first biodiesel industry buys soybean and converts this type of oil to biodiesel. The second industry converts other types of vegetable oils and fats into biodiesel. Both industries compete in the market for biofuels. They are also active agents in the markets for primary inputs and intermediate inputs, except for land. Note that these industries do not produce any byproduct because they covert vegetable oils and fats into biodiesel.

Modified model structure for the livestock sector

The FAO paper [6, 7] uses a multi-level nesting structure for the demand for animal feedstuffs in the livestock industry which brings more flexibility into this part of the model. We followed and modified this nesting structure to adjust the demand of livestock industry for the additional new feed commodities (two types of oilseeds and two types of meals). Figure 1 depicts the new nesting structure developed for this work. At the lower level of this nesting structure soybeans and soybean meals are mixed in one nest and other oilseeds and other meals are combined in another nest. At the next level (soybeans-soybean meal) and (other oilseeds-other meals) are combined to generate a protein feed. At this level DDGS and coarse grains are combined to create an energy feed as well. At a higher level the protein and energy feed ingredients are combined. At this level other crops also are bundled together. The livestock industry receives some inputs from processed livestock industry as well, and these materials are bundled together at the third level as well. Finally, all feed ingredients are combined to create the feed composite.

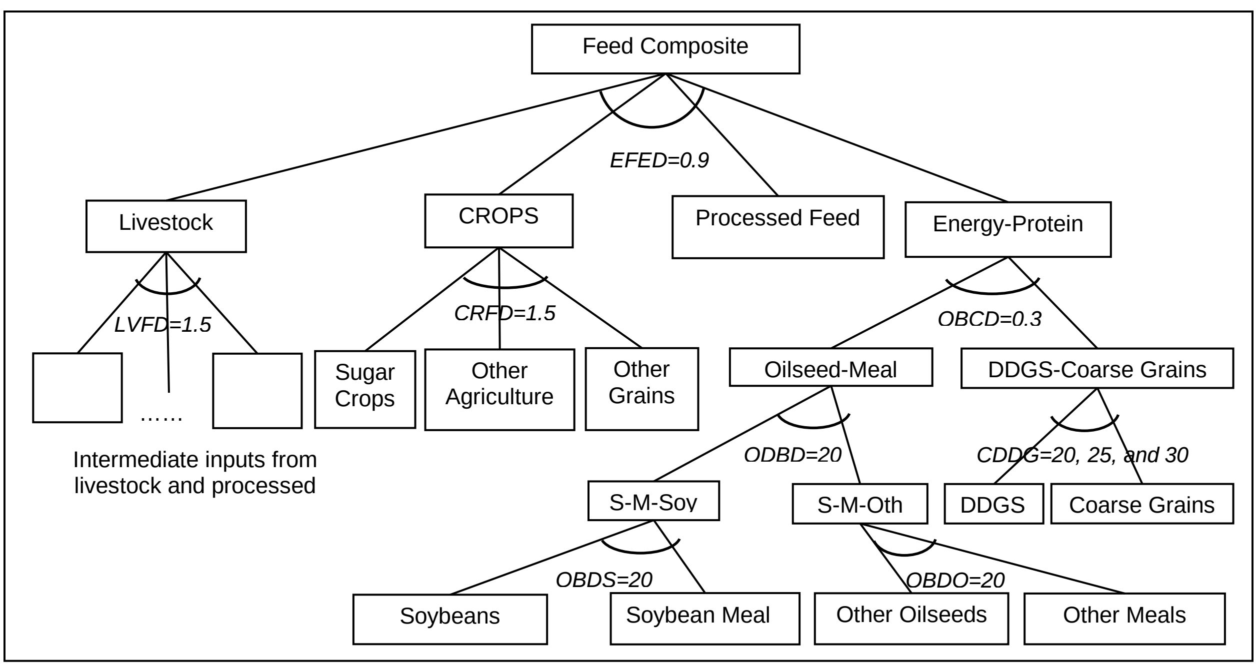


Figure 1. Structure of nested demand for feed in livestock industry

We assigned elasticities of substitution to the different components of the demand for feed to replicate changes in the prices of DDGS and meals in the US and EU during the time period of 2001-2006 [7]. In addition, we developed several experimental simulations and sensitivity tests to calibrate displacement ratios among DDGS, grains, oilseeds, and oilseed meals according to values from the literature in this area. These elasticities of substitution are depicted in Figure 1.

Revised land conversion factor for new cropland

The ratio of marginal and average productivities measures the productivity of new cropland versus the productivity of existing cropland. In GTAP, the parameter for this ratio is called ETA. In our earlier work we assumed that ETA = 0.66 in all regions and agro-ecologic zones. In the new approach, we use a set of regional ETAs at the AEZ level which is obtained from a bio-process-based biogeochemistry model, Terrestrial Ecosystem Model (TEM) [9] along with spatially referenced information on climate, elevation, soils, and vegetation land use data. The new regional ETAs vary across the world and among AEZs. The new estimated ETA values are now included in the model by country and AEZ.

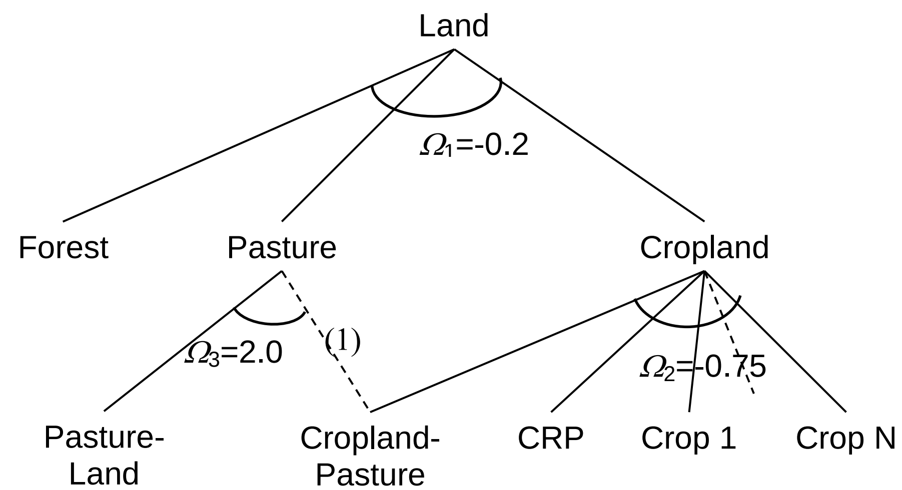
Incorporate cropland pasture for US and Brazil and CRP for US

Birur [10] added two new land categories of cropland-pasture and U.S. Conservation Reserve Program lands into land supply. Tyner et al. [3] followed and improved this work to incorporate these types of land into the land supply of the new GTAP-BIO model. Figure 2 represents the new structure of land supply in the modified model. To create this link we introduced an industry into the GTAP framework which uses only cropland-pasture as an input and sells its output (land) to the livestock industry.

In the new land supply tree cropland pasture and unused cropland (mainly CRP) are explicitly defined as components of cropland. CRP land mainly generates environmental benefits. Hence, this type of land is introduced as an input into the sector which provides these services (i.e. Oth_Ind_Se). Cropland-pasture and pasture are inputs into the livestock industry. To model the use of these two types of land in the livestock industry and in order to facilitate transition of cropland-pasture from livestock industry to crop production and vice versa, a dummy industry is added to the model which uses cropland-pasture as an input and sells its output to the livestock industry. This industry competes in the land market with crops. We do not use CRP land in this analysis. While the data is in the model, it has not been thoroughly tested.

Endogenous yield adjustment for cropland pasture

Conversion of cropland-pasture into crop production will increase the opportunity costs of using these lands as an input in livestock industry, which consequently will lead farmers to improve productivity of their cropland. We received comments on our previous work suggesting that the increased use of land for biofuels would lead to investments in increased productivity as land rents increased. This led us to define a module to link productivity of cropland with its rent [11]. This module determines changes in productivity of cropland pasture according to its rent and an elasticity parameter which is added to the model parameters. This elasticity calculates cropland pasture yield change with respect to changes in the rent of cropland pasture. In this work we assigned values of 0.4 and 0.2 to the yield elasticity related to the cropland-pasture areas of US and Brazil, respectively. Other regions do not have this category of land. This parameter is somewhat analogous to the price-yield elasticity for crop commodities. In the latter case, the yield of the crop increases as the price of the crop increases, and in this case the productivity of cropland pasture increases as its rent increases. This is one of those cases where economic logic tells us that some positive value is appropriate for this parameter, but we do not have an empirical basis for what number to use.



(1) In this land supply tree Ω_1 and Ω_2 are transformation elasticities and Ω_3 is the elasticity of substitution between pasture land and cropland pasture in the livestock industry

Figure 2. Land cover and land use activities in the GTAP-BIO-ADV

Greater flexibility in cropland switching in US

Prior to 2000, government programs and values of government policy variables such as the loan rate and target price were more important in determining acreage shifts among crops, and crop prices were less important. The GTAP parameter that helps determine the extent of acreage shift in response to relative crop prices was calibrated on historical data. Given the recent observations on crop acreage shifts, it seems that farmers now respond to the relative crop prices more than what we observed in the past. In this analysis, we asked the question of whether there is any difference in farmers' reactions to crop price changes in the past decade and earlier periods. To answer this question we estimated acreage response to changes in soybean and corn returns per acre over different decades prior to 2000 and for 2000-2010. The following regression shows the results for the time period of 2000-2010:

ΔHarvested corn area (acres)$_{(t)}$ = 1.388 + 0.084 ΔCorn revenue/acre$_{(t-1)}$ – 0.138 ΔSoybean revenue/acre$_{(t-1)}$

The static *t* values for the independent variables of this regression are 2.9 and 3.0 respectively, and the adjusted R^2 is 0.44. Clearly, for the 2000-2010 period, changes in corn and soybean revenues were a major driver of changes in corn acres. We did the same regressions for prior periods and found no significant relationship. As the literature suggests, in prior periods, government policy was a major driver, and now it is commodity prices and revenue. For these reasons, we increased the magnitude of the land supply transformation elasticity among the crop industries (including cropland pasture and CRP) from -.5 to -.75. Unfortunately, we cannot establish a direct link between the econometric evidence presented above and the appropriate value of this elasticity. We have observed more crop switching in recent years than the model gives with the lower elasticity, so it seemed appropriate to increase the value. In the future, we will continue to test the sensitivity of this parameter.

Data modifications

Update to GTAP version 7

Recently, version 7 of GTAP database, which depicts the world economy in 2004 was published [12]. However, this database does not include biofuel industries. In addition its aggregation level is not appropriate for this work which aims to evaluate the land use consequences of soybean biodiesel. Taheripour and Tyner [11, 13] introduced biofuels into this data set. However, that database uses an aggregation level which is not suitable for this work. To accomplish the objective of this research which concerns the land use consequences of US corn ethanol, US soy biodiesel, and Brazilian sugarcane ethanol, we modify the database developed by Tyner and Taheripour to make it consistent with the goals of this research. The database used in this research covers 19 regions, 33 industries and 37 commodities. See Appendix A for details. To create this database we followed the steps mentioned in Taheripour and Tyner except for the following items:

- The second generation of biofuels are introduced into the database,
- The *osd* sector is divided into two industries of *Soybeans* and *Other_Oilseeds*,
- The *vol* industry divided into two industries of *Vol_Soy* and *Vol_Oth*,
- We incorporated two biodiesel industries of *Biod_Soy* and *Biod_Oth*.

In what follows we explain the splitting processes which we followed to separate soybeans, soybean oil and meals and soy-biodiesel from their original parent sectors.

Separate soybeans from other oilseeds

To separate soybeans from other types of oilseeds we collected data on the production and harvested areas of soybeans at the global scale and then used the *SplitCom* program to breakdown the *osd* industry which covers all types of oilseeds into two new sectors of *soybeans* and *other oilseeds*. We did the split process based on the production shares of these products in total product of *osd (see Table 1)*. In this process we first allow the system to decide the trade share. Then we changed the trade shares of the new products in a repeating split process to move towards the actual observations on soybean trade and at the same time keep the database in balance.

Separate soybean oil and meal from other vegetable oils and meals

Table 1. Share of soybeans in total oilseeds production

Region	Soybeans	Other seeds	Total
1 USA	95.5	4.5	100.0
2 EU27	3.1	96.9	100.0
3 BRAZIL	92.2	7.8	100.0
4 CAN	26.3	73.7	100.0
5 JAPAN	87.9	12.1	100.0
6 CHIHKG	35.2	64.8	100.0
7 INDIA	21.9	78.1	100.0
8 C_C_Amer	3.4	96.6	100.0
9 S_o_Amer	78.3	21.7	100.0
10 E_Asia	90.9	9.1	100.0
11 Mala_Indo	0.5	99.5	100.0
12 R_SE_Asia	2.8	97.2	100.0
13 R_S_Asia	0.6	99.4	100.0
14 Russia	9.7	90.3	100.0
15 Oth_CEE_CIS	10.5	89.5	100.0
16 Oth_Europe	7.7	92.3	100.0
17 MEAS_NAfr	5.1	94.9	100.0
18 S_S_AFR	3.5	96.5	100.0
19 Oceania	1.6	98.4	100.0

Source: Authors' estimates.

To separate soybean oils and meals from other types of vegetable oils fats and meals we collected data on the production of these commodities and evaluated them at world prices. Then we obtained the share of soybean oil and meal in total production of all types of vegetable oils fats and meals. In the next step, we used the *SplitCom* program to breakdown the *vol* industry which covers all types of vegetable oils fats and meals into two new sectors of *Vol_Soy* and *Vol_Oth*. We established the split process based on the production shares of these products in total product of *vol (see Table 2)*.

In this process we first allow the system to decide the trade share. Then we changed the trade shares of the new products in a repeating split process to move towards the actual observations on soybean trade that keeps the database in balance as well. We finally, separated the share of meals in total outputs of each of these industries (see Table 3).

Separate soybean biodiesel from other types of biodiesel

In 2004 the EU members and US were the major producers of biodiesel. In this year 17.7% and 86% of the total biodiesel produced in these two regions were from soybean, respectively. Taheripour and Tyner [11, 13] introduced total biodiesel produced into the GTAP database. We accomplished this task for two types of biodiesel: *Biod_Soy* and *Biod_Oth*. The first industry uses soybean to produce biodiesel and the second one uses other types of vegetable oils and fats.

Table 2. Share of soybean oil and meal in total values of vegetable oils, fats, and meals

Region	Soybeans	Other seeds	Total
1 USA	77.1	22.9	100.0
2 EU27	19.3	80.7	100.0
3 BRAZIL	89.2	10.8	100.0
4 CAN	21.6	78.4	100.0
5 JAPAN	41.3	58.7	100.0
6 CHIHKG	44.9	55.1	100.0
7 INDIA	19.8	80.2	100.0
8 C_C_Amer	70.2	29.8	100.0
9 S_o_Amer	82.3	17.7	100.0
10 E_Asia	5.0	95.0	100.0
11 Mala_Indo	1.1	98.9	100.0
12 R_SE_Asia	29.6	70.4	100.0
13 R_S_Asia	1.1	98.9	100.0
14 Russia	12.2	87.8	100.0
15 Oth_CEE_CIS	12.8	87.2	100.0
16 Oth_Europe	38.1	61.9	100.0
17 MEAS_NAfr	26.5	73.5	100.0
18 S_S_AFR	4.2	95.8	100.0
19 Oceania	1.3	98.7	100.0

Source: Authors' estimates

Revised emission factors to be provided by CARB

The emission factors (from whatever source) are used outside of the GTAP model. GTAP provides the land use changes by region, and the emission factors are multiplied by these land use changes to get the associated emissions. This report is restricted to land use changes alone.

Table 3. Share of meals in total sale values of Vol_Soy and Vol_Oth industries

	Vol_Soy			Vol_Oth		
	Oil	**Meal**	**Total**	**Oil**	**Meal**	**Total**
1 USA	44.6	55.4	100.0	62.7	37.3	100.0
2 EU27	68.1	31.9	100.0	80.3	19.7	100.0
3 BRAZIL	62.5	37.5	100.0	79.6	20.4	100.0
4 CAN	53.6	46.4	100.0	69.9	30.1	100.0
5 JAPAN	55.4	44.6	100.0	73.0	27.0	100.0
6 CHIHKG	48.1	51.9	100.0	66.7	33.3	100.0
7 INDIA	71.1	28.9	100.0	77.0	23.0	100.0
8 C_C_Amer	59.5	40.5	100.0	77.8	22.2	100.0
9 S_o_Amer	66.3	33.7	100.0	78.6	21.4	100.0
10 E_Asia	55.0	45.0	100.0	66.3	33.7	100.0
11 Mala_Indo	61.9	38.1	100.0	77.2	22.8	100.0
12 R_SE_Asia	63.1	36.9	100.0	80.0	20.0	100.0
13 R_S_Asia	68.9	31.1	100.0	72.6	27.4	100.0
14 Russia	67.1	32.9	100.0	81.7	18.3	100.0
15 Oth_CEE_CIS	67.3	32.7	100.0	80.1	19.9	100.0
16 Oth_Europe	70.1	29.9	100.0	80.5	19.5	100.0
17 MEAS_NAfr	69.7	30.3	100.0	78.1	21.9	100.0
18 S_S_AFR	72.5	27.5	100.0	79.8	20.2	100.0
19 Oceania	69.6	30.4	100.0	82.6	17.4	100.0

Source: Authors' estimates

Results

First we present results for the three pathways being revised in this analysis: US corn ethanol, US soy biodiesel, and Brazilian sugarcane. Then we present results for the two major sensitivity analyses accomplished here: price-yield elasticity, and food consumption change due to higher prices.

<u>Land use impacts of US corn ethanol</u>

We model an increase in US corn ethanol production by 11.59 billion gallons per year[1] (bg/y). This increases US corn ethanol from its 2004 level, which is 3.41bg/y, to 15 bg/y. Resulting changes in land cover by region and land cover type are reported in the first three columns of Table 4. Global cropland expands by 2,126,261 hectares (ha) resulting in 290,637 ha of forest land loss and 1,835,267 ha of pasture loss. As expected, the largest cropland expansion is observed in US (1,002,512 ha), followed by

[1] In all experiments conducted in this work we keep production of other biofuels constant when we shock each type biofuel.

Sub Saharan Africa, EU27 and Canada. The largest forest land losses are observed in US, Canada, and EU. Pasture losses are widely distributed.

The additional cropland per 1000 gallons of expanded biofuel is a useful metric for comparison purposes across different models and biofuel feedstocks. Producing **1000 gallons of US corn ethanol requires 0.18 hectares of new cropland** of which 0.03 comes from forest land and 0.16 from pasture. If cropland pasture is included in the converted land base, the land needed becomes 0.31 ha/1000 gal.

Land use impacts of US soybean biodiesel

We model an increase in US soybean biodiesel of 0.812 billion gallons per year (bg/y). That number is based on the following calculations:

- 2004 soy and total biodiesel production was 0.024 and 0.028 bil. gal. respectively
- The increment from 0.028 to one bil. gal. is 0.972 bil. gal.
- Soy is 86% of that (the 2004 ratio), so the soy amount is 0.836
- The soy Δ is the difference between this and 2004, which is 0.812.

Changes in land cover by region and land cover type obtained from this simulation are reported in the second block of Table 4. Global cropland expands by 143,189 ha resulting in reforestation by 2,179 ha and loss of 145,369 ha of pasture land. As expected, the largest cropland expansion is observed in the US (97,418 ha), followed by Brazil and South America, which are the main soybean producers across the world. The largest forest land losses are observed in US and Brazil. Producing biodiesel from soybean causes reforestation in many regions across the world. This is due to the fact that production of soybean biodiesel in the US eventually increases exports of US soybean meals to other countries. This ultimately, reduces the demand for domestic meal in other regions across the world which leads to reduction in the demand for cropland and reforestation in those regions. Producing **1000 gallons of US soybean biodiesel requires 0.18 hectares of new cropland** which mainly comes from pasture land with no significant change in forest area at the global scale. Including cropland pasture in the land base increases the land needed to 0.43 ha/1000 gal.

Land use impacts of Brazilian sugarcane ethanol

We model the increase of Brazilian sugarcane ethanol production from 2004 level, of 3.989 billion gallons per year (bg/y), by 3bg/y, and simultaneous increase in US imports of Brazilian sugar cane ethanol from 0.184209 bgy by 1 bgy up to 1.184209 bgy. Thus, Brazilian production increases by 3 bg/y and exports to the US by 1 bg/y. Production of US biofuels (grains ethanol and biodiesel) is fixed at the baseline level.[2]

[2] The expansion of sugarcane ethanol production in Brazil is modeled with production subsidy. Increase in US imports of the sugarcane ethanol from Brazil is modeled with consumption subsidy on imported sugar cane ethanol. US biofuels production is fixed with consumption subsidy for domestic coarse grains ethanol an biodiesel. US consumers then pay a tax on liquid fuel mix to offset costs of subsidies to imported ethanol and domestic biofuels. The alternative way to fix production in US would be though output subsidy.

Table 4. Land cover changes due to expansion of US corn ethanol, US soybean biodiesel, and sugarcane ethanol in Brazil, (hectares)

Region	Corn Ethanol			Soybean Biodiesel			Brazil sugarcane ethanol		
	forest	cropland	pasture	forest	Cropland	pasture	forest	cropland	pasture
1 USA	-352,528	1,002,512	-649,984	-43,620	97,418	-53,798	-5,344	37,296	-31,904
2 EU27	-81,184	127,848	-46,640	1,352	2,620	-3,972	-33,696	38,080	-4,404
3 BRAZIL	-3,648	88,596	-84,928	-1,923	20,506	-18,583	-28,720	221,760	-193,040
4 CAN	-115,112	172,312	-57,192	9,203	-12,489	3,287	-24,664	32,132	-7,484
5 JAPAN	-3,076	3,530	-452	-13	72	-58	-438	454	-18
6 CHIHKG	17,648	55,104	-72,736	3,446	-1,501	-1,945	-480	8,496	-8,000
7 INDIA	-1,918	4,768	-2,835	1,659	-2,509	849	-660	1,504	-831
8 C_C_Amer	32,328	20,992	-53,320	4,583	2,676	-7,260	5,472	2,312	-7,776
9 S_o_Amer	81,560	65,520	-147,104	6,279	17,006	-23,284	-760	14,496	-13,712
10 E_Asia	3,984	806	-4,784	264	-11	-253	316	68	-384
11 Mala_Indo	7,388	-3,840	-3,510	141	115	-256	308	200	-501
12 R_SE_Asia	2,496	2,640	-5,134	889	-532	-357	-360	272	87
13 R_S_Asia	-1,756	23,424	-21,668	418	-2,322	1,904	-478	4,992	-4,516
14 Russia	189,520	8,752	-198,216	15,999	-3,814	-12,187	23,488	4,392	-27,864
15 Oth_CEE_CIS	-21,244	105,112	-83,840	919	2,071	-2,990	-5,764	22,472	-16,672
16 Oth_Europe	-86	1,649	-1,564	126	14	-140	-44	303	-258
17 MEAS_NAfr	-80	86,008	-85,936	58	2,430	-2,488	-263	15,964	-15,712
18 S_S_AFR	-44,144	274,400	-230,080	1,253	14,330	-15,583	-23,744	57,648	-33,856
19 Oceania	-785	86,128	-85,344	1,146	7,108	-8,254	-1,066	8,852	-7,744
Total	-290,637	2,126,261	-1,835,267	2,179	143,189	-145,369	-96,897	471,693	-374,589
Cropland Pasture (CP)	-	1,438,468	-	-	202,759	-	-	727,308	-
Total with CP	-	3,564,729	-	-	345,948	-	-	1,199,001	-
ha/1000 gallon	-0.03	0.18	-0.16	0.00	0.18	-0.18	-0.03	0.16	-0.12
ha with CP/1000 gallon	-	0.31	-	-	0.43	-	-	0.40	-

Changes in land cover by region and land cover type are reported in the last three columns of Table 4 and Brazilian harvested area changes in Table 5. Global cropland expands by 471,693 ha resulting in 96,897 ha of forest land loss and 374,589 ha of pasture loss. As expected, largest cropland expansion is observed in Brazil (221,760 ha), followed by Sub Saharan Africa, EU27, and US. The largest forest land losses are observed in Brazil, EU27 and Canada. The largest pasture losses are observed in Brazil, US, and Sub Saharan Africa. **1000 gallons of Brazilian sugarcane ethanol requires 0.16 ha of cropland**, of which 0.03 comes from forest land and 0.13 from pasture. Including cropland pasture in the land base increases this number to 0.40 ha/1000 gal.

Table 5. Brazilian harvested area changes due to expansion of sugarcane ethanol in Brazil, (hectares)

Cropland use	Harvested area changes, ha
Paddy_Rice	-32,291
Wheat	-100,679
CrGrains	-163,669
Soybeans	-339,964
Oth_Oilseeds	-15,088
Sugar_Crop	1,727,340
OthAgri	-166,176
Cropland pasture	-687,710
Total	221,762

In the Ferreira-Filho and Horridge [14, 15] analysis, sugarcane ethanol expansion from 2009 to 2020 results in an additional 680 Kha of sugar cane, 150 Kha of which comes from other crops, 380 Kha from pasture, 30 Kha from planted forests and 120 Kha from unused land. Converting these to a per sugarcane hectare basis, suggests that by 2020 each additional sugar cane hectare will require 0.56 ha of pasture, 0.04 ha of planted forest, and 0.18 of unused land converted, together resulting in 0.78 ha of land converted per additional hectare of sugarcane. Ferreira-Filho and Horridge [14] use a dynamic model and calculate average per year conversions between 2009 and 2020. They report 0.47 ha of pasture and 0.14 ha of unused land are required for each additional hectare of sugar cane in Brazil. In our analysis, 3 bg/y expansion of sugar cane ethanol requires additional 1,727,340 ha of sugar cane in Brazil (Table 5). This additional area comes from expansion of total cropland (221,762 ha), as well as reduction in other uses of cropland including cropland pasture which is reduced by 687,710 ha (Table 5). Taking into account that additional cropland in Brazil (221,762 ha) partly comes from pasture (374,589 ha) and forest, we can construct a metric similar to one used by Ferreira-Filho and Horridge. Because the GTAP model used in this analysis is static and allows comparison between initial and new (with expanded sugarcane production) equilibria, the cumulative metric from Ferreira-Filho and Horridge is appropriate for comparison. In our analysis, an additional 0,11 hectares of pasture (193,040/1,727,340), 0.40 (687,710/1,727,340) ha of cropland-pasture, and 0.02 ha (28,720/1,727,340) of forest are converted for each additional hectare of sugarcane ethanol, together resulting in 0.53 ha of land converted per additional hectare of sugarcane.[3] Our result for managed forests (0.02 vs. 0.04) and pasture (0.51 vs. 0.56) conversions are close to results reported in Ferreira-Filho and Horridge. The total land converted in Brazil in Ferreira-Filho and Horridge is 0.60 ha/ha (0.56+0.04), excluding conversion of unused land, compared to our 0.53. In the case of unused land converted, the comparison is problematic because unused land is not included in the GTAP analysis.

Sensitivity analysis on assumption regarding food consumption changes

Expansion of biofuels results in increase of food prices worldwide for most of the food items and reduction in consumption in some regions. Appendix B Tables B-1 to B-3 show impacts of US corn ethanol, US soybean biodiesel, and Brazilian sugarcane ethanol on the food consumption by food category and region in percent changes. Appendix B Tables B-4 to B-6 report percent changes in global export prices and regional market prices for 18 food commodities due to biofuel production. The results in these tables are done with the base case GTAP assumptions and parameters.

These results indicate that biofuels have a minor impact on changes in food consumption, with the largest impact being in the US (0.27%). For the case of US corn ethanol, regions such as US, Central America, South America, Russia, and North Africa and Middle East are expected to observe the higher rates of reductions in food consumption. US soybean biodiesel production and Brazilian sugarcane ethanol have no major impact on food consumption. US corn ethanol increases prices more than other cases due to the larger size of corn ethanol production shock. The largest price increase for corn ethanol is observed in US coarse grain price (7.1%). The largest price increase for the case of soybean biodiesel is observed in US soybean oil (15.5%). The largest price increase for Brazilian sugarcane is 6.2%.

To address uncertainty in changes in food demand triggered by biofuels expansion, we considered two additional scenarios. In the first scenario, we fix food consumption with a series of country-by-commodity subsidies only in developing countries. In the second scenario we fix food consumption globally. Detailed results for land cover changes in the two scenarios as well as our central case are reported in Appendix B Tables 7-9. The global summary is shown in Figures 3-5. In this analysis, US, EU27, Canada, Japan, Russia, Other Europe and Oceania are developed countries in this analysis.

[3] This calculation is based on harvested sugarcane area, not cultivated sugar cane area, and an assumption that these two metrics are very close for the case of sugarcane in Brazil.

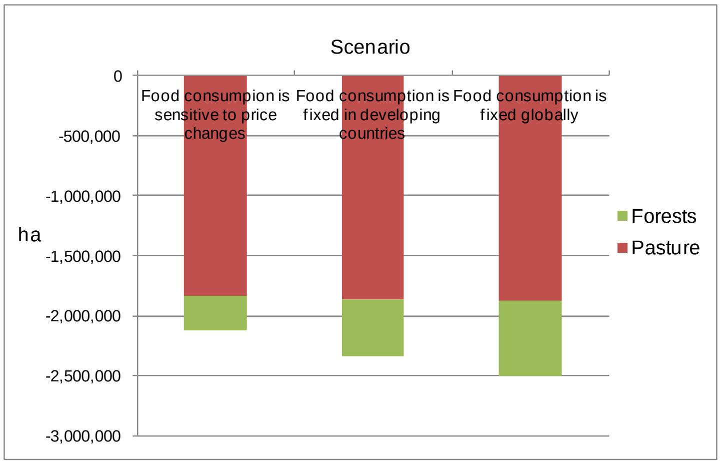


Figure 3. Summary of the sensitivity of land cover changes due to expansion of US coarse grains ethanol with respect to assumption about changes in food demand, ha

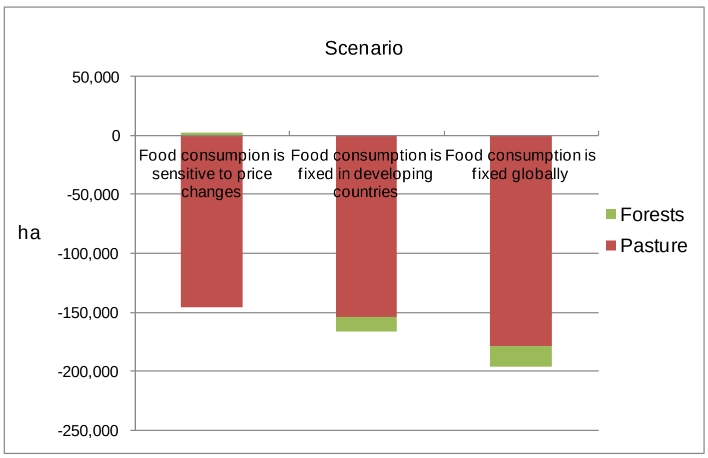


Figure 4. Summary of the sensitivity of land cover changes due to expansion of US soy biodiesel with respect to assumption about changes in food demand, ha

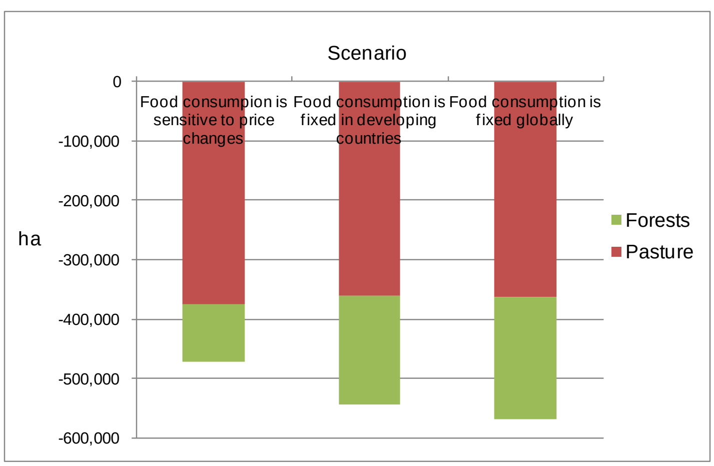


Figure 5. Summary of the sensitivity of land cover changes due to expansion of Brazilian sugarcane ethanol with respect to assumption about changes in food demand, ha

In the case of corn ethanol, pasture land converted is not very sensitive to the assumption about changes in food demand. However, forest land area is very sensitive increasing from 290 Kha converted in our central case to 629 Kha converted when global consumption does not change. This is more than twice as high. It is similar for sugarcane ethanol: pasture converted is not sensitive, but forest land converted increases as food demand becomes more inelastic. Interesting, fixing food in the developed world in addition to fixing food in the developing world (going from scenario 2 to 3 in Figure 6) increases global cropland requirement only slightly. In the case of soy biodiesel, both forest and pasture are affected by the assumption about food demand and expand in the presence of inelastic food demand.

<u>Sensitivity analysis on the yield-to-price elasticity</u>

We also consider land cover changes triggered by biofuel expansion under alternative assumptions about the yield-to-price parameter. The experiments are: 1) increase in US corn ethanol production by 11.59 bgy from 2004 levels; 2) increase in US soy biodiesel production by 0.812 bgy from 2004 levels; and 3) increase in sugar cane ethanol production by 3 bgy with simultaneous increase in US imports of sugarcane ethanol by 1 bgy.

Keeney and Hertel [16] review the literature on yield response to corn prices and find the simple average of recent studies gives a yield elasticity of 0.25. In the past, land use change analysis with GTAP utilized this price-yield elasticity of 0.25, meaning that a 10% increase in price leads to a 2.5% increase in yield for a given crop, everything else being equal.

It must be born in mind that this elasticity, like many parameters in GTAP, needs to represent the medium term. That is, the comparative static GTAP solution covers a period of adjustment of 5-8 years. Since Hayami and Ruttan (1985), economists have recognized induced technical change in agriculture. There is ample evidence in the literature that research and development (seeds, machinery, infrastructure, etc.) follows crop profitability. And certainly crop profit depends in part on crop price. Hence, there is no doubt that there is a yield response to higher crop prices. Estimating the parameter accurately will be very difficult. We know that a one year estimate is totally inappropriate. We also know that a longer time period would have a larger response (elasticity) than a shorter period. We do not in reality know if the appropriate value for the yield-to-price elasticity is 0.25 or higher or lower. However, CARB has requested that we do sensitivity analysis only for lower values of 0.05 and 0.10, so that is what is reported in this paper.

The detailed results for US coarse grains ethanol, US soy biodiesel and Brazilian sugarcane ethanol are reported in Appendix C Tables 1-3. The global summary of the sensitivity analysis is shown in Figures 6-8. For all three feedstocks, reduction in the elasticity from 0.25 to 0.1 has a significant effect on the additional cropland requirement. For corn, global cropland requirement increases from 2.1 mil. Ha to 2.8 mil ha (34%) with most of the increase coming from pasture land. As the parameter is further reduced from 0.1 to 0.05, global cropland requirement increases from 2.8 mil. Ha to 3.2 mil. Ha (+14%).

For soy biodiesel, global cropland requirement increases from 143 Kha to 201 Kha (40%) when parameter is reduced from 0.25 to 0.1. An interesting observation regarding soy biodiesel is that in our base case, almost all additional cropland comes from pasture. Forest land is reduced in US, but expands in other regions, with a small net positive change globally. As yield sensitivity to price is reduced from 0.25 to 0.1, additional demand for cropland is satisfied by conversion not only of pasture, but also global forests. As the parameter is further reduced from 0.1 to 0.05, the global cropland requirement slightly increases from 201 Kha to 229 Kha (+14%).

In case of sugarcane ethanol, reduction in the yield-to-price elasticity from 0.25 to 0.1 results in cropland requirement increase from 471 Kha to 604 Kha (28%). Further reduction of the parameter from 0.1 to 0.05 results in cropland requirement increase from 604 Kha to 670 Kha (+11%). Most of the increase in cropland requirement is fulfilled by pasture. Of the three biofuels considered, sugarcane ethanol total cropland area requirement is least sensitive to the yield-to-price elasticity.

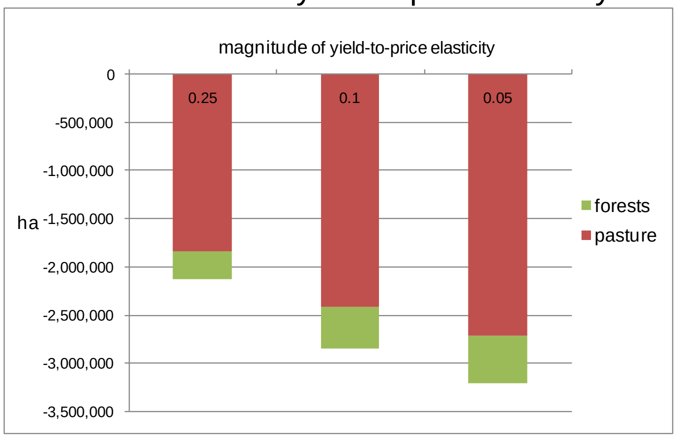


Figure 6. Summary of the sensitivity of land cover changes due to expansion of US corn ethanol with respect to yield-to-price elasticity, ha

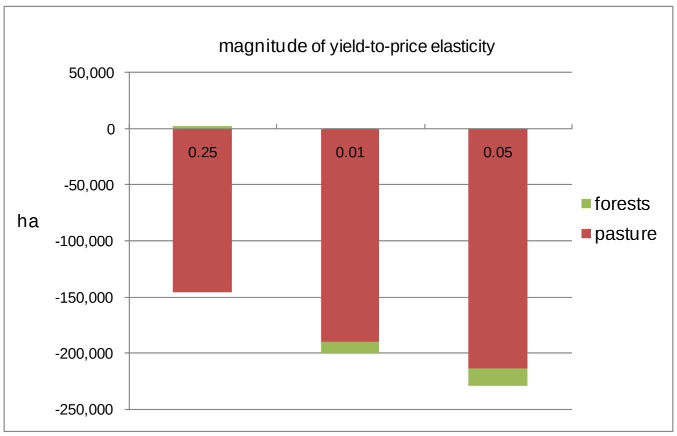


Figure 7. Summary of the sensitivity of land cover changes due to expansion of US soy biodiesel with respect to yield-to-price elasticity, ha

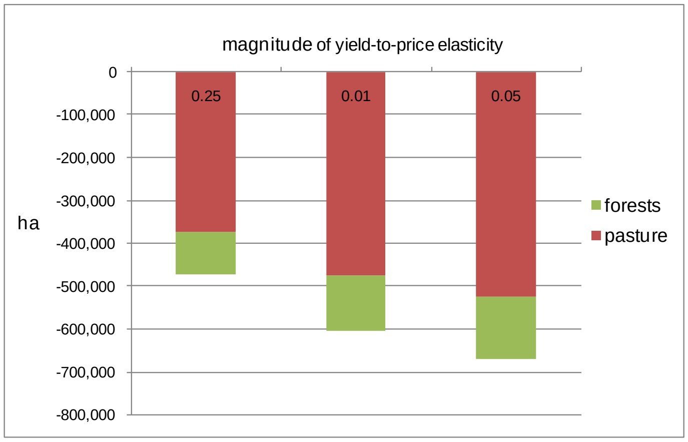


Figure 8. Summary of the sensitivity of land cover changes due to expansion of Brazilian sugarcane ethanol with respect to yield-to-price elasticity, ha

Sensitivity analysis on the cropland transformation elasticity

As indicated above, the current base value for this elasticity is -0.75. CARB requested that the simulations also be done with the previous value of -0.50. The detailed results of this sensitivity analysis are reported in Appendix D. Table 6 provides a summary of the results. The bottom line is that there are not major differences between the two assumptions. In general, cropland increase goes up slightly, forest use diminishes, and pasture use increases. We believe the -0.75 value provides a more realistic representation of crop switching in today's world.

Table 6. Summary of the sensitivity of land cover changes due to expansion of biofuels with respect to cropland transformation elasticity values (hectare)

Biofuel Case		Transformation Elasticity = -0.75			Transformation Elasticity = -0.5		
		forest	Cropland	pasture	forest	Cropland	Pasture
US corn ethanol	Area	-290,637	2,126,261	-1,835,267	-244,643	2,242,346	-1,997,737
	ha/1000 gall	-0.03	0.18	-0.16	-0.02	0.19	-0.17
US soy biodiesel	Area	2,179	143,189	-145,369	11,936	145,775	-157,664
	ha/1000 gall	0.00	0.18	-0.18	0.01	0.18	-0.19
Brazilian Sugarcane ethanol	Area	-96,897	471,693	-374,589	-37,167	549,994	-512,993
	ha/1000 gall	-0.03	0.16	-0.12	-0.01	0.18	-0.17

Sensitivity analysis on endogenous productivity increase for cropland pasture

As explained above, the endogenous increase in cropland pasture is simply a parameter to permit cropland pasture productivity to increase as its rent increases. That link exists in the real world, but is difficult to quantify. In addition to the base values of

0.4 and 0.2 for the US and Brazil, CARB requested sensitivity analysis using values of zero for both regions. The detailed results are reported in Appendix E. All of the changes are small except for some cases the percentage change in forest cover. Cropland increase goes down, forest change to cropland increases, pasture change to cropland decreases, and cropland needed per 1000 gallons of biofuel decreases slightly. The numerical results are summarized in Table 7.

Table 7. Summary of the sensitivity of land cover changes due to expansion of biofuels with respect to endogenous productivity increase in cropland pasture (hectare)

Biofuel Case		US=0.4 and Brazil=0.2			US=0.0 and Brazil=0.0		
		forest	Cropland	pasture	forest	Cropland	Pasture
US corn ethanol	Area	-290,637	2,126,261	-1,835,267	-552,610	2,019,458	-1,466,719
	ha/1000 gall	-0.03	0.18	-0.16	-0.05	0.17	-0.13
US soy biodiesel	Area	2,179	143,189	-145,369	-32,236	130,157	-97,844
	ha/1000 gall	0.00	0.18	-0.18	-0.04	0.16	-0.12
Brazilian Sugarcane ethanol	Area	-96,897	471,693	-374,589	-190,255	455,906	-265,832
	ha/1000 gall	-0.03	0.16	-0.12	-0.06	0.15	-0.09

Conclusions

Table 8 provides a comparison of these results with some of the previous results. It is important to recognize that the analyses were done under different assumptions on key parameters, different sizes of shocks, etc., so the comparison may be of limited use. It is mainly provided to summarize differences in one key indicator – hectares of land needed per 1000 gallons of biofuel. From Table 8, it is clear that these results are in line with the 2010 Purdue results [3] and lower than the CARB 2009 results [17] for US corn ethanol. These base case results are considerably lower than the CARB 2009 results for US soy biodiesel and the preliminary Purdue results in January 2010. The new results are also considerably lower for Brazilian sugarcane. For soy biodiesel, the difference is mainly due to the more accurate handling of soybeans and soybean meal as well as soy biodiesel in the new version of the model. For Brazilian sugarcane, it is probably mainly due to the incorporation of cropland pasture in the data base.

The last column in Table 8 provides the land needed per 1000 gallons of biofuel including in the land base the cropland pasture converted to other crops. In the past, cropland pasture has been considered as part of cropland (and is modeled that way in GTAP), so "conversion" of cropland pasture was not counted in emissions calculations. It is our understanding that now CARB intends to apply emission factors to cropland pasture, so we present here two measures – one without cropland pasture in the base and one with cropland pasture in the base. All three crops use a good bit of cropland pasture.

The food consumption sensitivity results indicate that the land cover change is somewhat sensitive to changes in the food consumption assumption. However, the restrictions on food consumption in the alternative cases are pretty severe, and the magnitude of changes is relatively small.

Table 8. Comparison with Previous Estimates of Land Cover Change (ha/1000 gal. biofuel)

Biofuel	CARB 2009	Purdue 2010	Current Results	Results with CP
US corn ethanol	0.29	0.13 – 0.22	0.18	0.31
US soy biodiesel	0.63	0.94[a]	0.18	0.43
Brazilian sugarcane	0.55	-	0.16	0.40

[a] Preliminary Purdue result provided to CARB in January 2010

The results are quite sensitive to changes in the yield-price elasticity. While we believe that there is in the real world a response in yield to price over the medium term, there is no solid empirical evidence on what that elasticity should be, so sensitivity analysis is appropriate.

The results are not very sensitive either to the cropland transformation elasticity or the endogenous cropland yield elasticity assumptions. The endogenous cropland productivity elasticity is more important for cellulosic biofuels that are not covered in this analysis.

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Appendix A

Table A1. Regions and their members

Region	Description	Corresponding Countries in GTAP
USA	United States	Usa
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, grc, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
BRAZIL	Brazil	Bra
CAN	Canada	Can
JAPAN	Japan	Jpn
CHIHKG	China and Hong Kong	chn, hkg
INDIA	India	Ind
C_C_Amer	Central and Caribbean Americas	mex, xna, xca, xfa, xcb
S_o_Amer	South and Other Americas	col, per, ven, xap, arg, chl, ury, xsm
E_Asia	East Asia	kor, twn, xea
Mala_Indo	Malaysia and Indonesia	ind, mys
R_SE_Asia	Rest of South East Asia	phl, sgp, tha, vnm, xse
R_S_Asia	Rest of South Asia	bgd, lka, xsa
Russia	Russia	Rus
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union	xer, alb, hrv, xsu, tur
R_Europe	Rest of European Countries	che, xef
MEAS_NAfr	Middle Eastern and North Africa	xme,mar, tun, xnf
S_S_AFR	Sub Saharan Africa	Bwa, zaf, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss
Oceania	Oceania countries	aus, nzl, xoc

Table A2. List of Industries and Commodities in the New Model

Industry	Commodity	Description	Name in the GTAP_BIOB
Paddy_Rice	Paddy_Rice	Paddy rice	Pdr
Wheat	Wheat	Wheat	Wht
CrGrains	CrGrains	Cereal grains	Gro
Soybeans	Soybeans	Soybeans	A portion of osd
Other Oilseeds	Other oilseeds	Non soybean oilseeds	A portion of osd
OthAgri	OthAgri	Other agriculture goods	ocr, pfb, v_f
Sugarcane	Sugarcane	Sugar cane and sugar beet	c-b
DairyFarms	DairyFarms	Dairy Products	Rmk
Ruminant	Ruminant	Cattle & ruminant meat production and	Ctl, wol
NonRum	Non-Rum	Non-ruminant meat production	oapl
ProcDairy	ProcDairy	Processed dairy products	Mil
ProcRum	ProcRum	Processed ruminant meat production	Cmt
ProcNonRum	ProcNonRum	Processed non-ruminant meat production	Omt
Forestry	Forestry	Forestry	Frs
Vol_Soy	Vol_Soy	Soybean oil	A portion of vol
	VOBPS	Soybean meals	A portion of vol
Vol_Oth	Vol_Oth	Non soybean vegetable oils and fats	A portion of vol
	VOBPO	Non soybean meals	A portion of vol
Proc_Rice	Proc_Rice	Processed rice	Pcr
Bev_Sug	Bev_Sug	Beverages, tobacco, and sugar	b_t, sgr
Proc_Food	Proc_Food	Processed food products	A portion of ofd
Proc_Feed	Proc_Feed	Processed animal feed products	A portion of ofd
OthPrimSect	OthPrimSect	Other Primary products	fsh, omn
Coal	Coal	Coal	Coa
Oil	Oil	Crude Oil	Oil
Gas	Gas	Natural gas	gas, gdt
Oil_Pcts	Oil_Pcts	Petroleum and coal products	p-c
Electricity	Electricity	Electricity	Ely
En_Int_Ind	En_Int_Ind	Energy intensive Industries	crpn, i_s, nfm, fmp
Oth_Ind_Se	Oth_Ind_Se	Other industry and services	atp, cmn, cns, ele, isr, lea, lum, mvh, nmm, obs, ofi, ome, omf, otn, otp, ppp, ros, tex, trd, wap, wtp
NTrdServices	BTrdServices	Services generating Non-C02 Emissions	wtr, osg, dwe
AdvfB-Misc	AdvfB-Misc	Bio-Gasoline produced from miscanthus	New
AdvfB-Swit	AdvfB-Swit	Bio-Gasoline produced from switchgrass	New
AdvfB-Stover	AdvfB-Stover	Bio-Gasoline produced from corn stover	New
AdvfE-Misc	AdvfE-Misc	Ethanol produced from miscanthus	New
AdvfE-Swit	AdvfE-Swit	Ethanol produced from switchgrass	New
AdvfE-Stover	AdvfE-Stover	Ethanol produced from corn stover	New
EthanolC	Ethanol1	Ethanol produced from grains	New
	DDGS	Dried Distillers Grains with Solubles	New
Ethanol2	Ethanol2	Ethanol produced from sugarcane	New
Biod_Soy	Soy Biodiesel	Biodiesel produced from soybean oil	New
Biod_Oth	Other biodiesels	Biodiesel produced from non-soybean oils and fats	New

Appendix B

Table B-1 Food consumption impacts of expansion of US corn ethanol (figures are in %)

Food category	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	-0.18	-0.06	-0.11	-0.12	-0.02	-0.03	-0.01	-0.30	-0.22	-0.06	-0.11	-0.02	-0.01	-0.20	-0.07	-0.08	-0.33	-0.12	-0.08
Wheat	-0.16	-0.05	-0.09	-0.12	-0.03	-0.03	0.00	-0.28	-0.26	-0.08	-0.16	-0.06	-0.03	-0.21	-0.06	-0.05	-0.36	-0.18	-0.11
CrGrains	-0.30	-0.06	-0.12	-0.48	-0.31	-0.05	0.00	-0.44	-0.35	-0.27	-0.10	-0.06	-0.04	-0.23	-0.09	-0.05	-0.44	-0.12	-0.28
Soybeans	-0.21	-0.12	-0.10	-0.19	-0.04	-0.04	-0.01	-0.41	-0.21	-0.18	-0.13	-0.10	-0.01	-0.22	-0.14	-0.05	-0.43	-0.13	-0.27
Oth_Oilseeds	-0.16	-0.05	-0.09	-0.12	-0.03	-0.04	0.00	-0.21	-0.18	-0.05	-0.07	-0.05	-0.01	-0.22	-0.08	-0.05	-0.33	-0.13	-0.09
Sugar_Crop	-0.27	-0.04	-0.06	-0.13	-0.02	-0.03	0.00	-0.23	-0.19	0.00	-0.10	-0.01	-0.01	-0.19	-0.04	-0.04	-0.30	-0.11	-0.07
OthAgri	-0.26	-0.06	-0.11	-0.19	-0.03	-0.04	0.00	-0.26	-0.23	-0.08	-0.09	-0.05	-0.01	-0.20	-0.08	-0.05	-0.34	-0.12	-0.09
Dairy_Farms	-0.41	-0.06	-0.07	-0.18	-0.16	-0.07	0.03	-0.50	-0.21	-0.09	-0.06	-0.04	0.00	-0.24	-0.08	-0.16	-0.42	-0.31	-0.06
Ruminant	-0.39	-0.05	-0.07	-0.19	-0.23	-0.07	0.03	-0.17	-0.19	-0.07	-0.09	-0.01	0.00	-0.23	-0.06	-0.17	-0.42	-0.29	-0.07
NonRuminant	-0.55	-0.01	0.00	-0.17	-0.15	-0.03	0.08	-0.12	-0.15	-0.10	-0.06	0.04	0.02	-0.24	-0.05	-0.11	-0.42	-0.27	-0.01
Proc_Dairy	-0.20	0.00	-0.01	-0.10	-0.03	-0.03	0.10	-0.20	-0.13	0.00	-0.06	0.04	0.02	-0.21	-0.04	-0.08	-0.39	-0.25	-0.02
Proc_Rum	-0.22	-0.01	-0.03	-0.09	-0.10	-0.02	0.11	-0.12	-0.13	-0.06	-0.07	0.04	0.02	-0.22	-0.04	-0.09	-0.38	-0.23	-0.02
proc_NonRum	-0.27	-0.01	0.00	-0.12	-0.05	-0.03	0.10	-0.13	-0.12	-0.07	-0.04	0.04	0.03	-0.25	-0.04	-0.09	-0.37	-0.27	-0.01
Bev_Sug	-0.18	-0.01	0.00	-0.07	-0.01	-0.01	0.03	-0.10	-0.10	0.02	-0.05	0.04	0.02	-0.21	-0.04	-0.09	-0.35	-0.17	-0.01
Proc_Rice	-0.08	-0.01	-0.05	-0.22	-0.01	-0.02	0.01	-0.15	-0.15	-0.06	-0.06	-0.01	0.00	-0.20	-0.03	-0.03	-0.31	-0.11	-0.01
Proc_Food	-0.17	-0.01	-0.02	-0.09	-0.06	-0.03	0.03	-0.15	-0.11	-0.03	-0.05	0.02	0.01	-0.21	-0.03	-0.08	-0.37	-0.18	0.00
Vol_Soy1	-0.36	-0.03	-0.02	-0.30	-0.31	0.04	0.04	-0.11	-0.14	-0.30	-0.11	0.03	-0.01	-0.19	-0.07	-0.13	-0.40	-0.21	-0.07
Vol_Oth1	0.11	0.03	0.05	0.03	0.07	0.06	0.05	-0.08	-0.10	-0.17	-0.02	0.06	0.03	-0.17	0.00	-0.04	-0.33	-0.17	0.04
Food consumption index	-0.21	-0.02	-0.03	-0.10	-0.04	-0.03	0.03	-0.18	-0.14	-0.04	-0.06	0.02	0.01	-0.22	-0.05	-0.08	-0.37	-0.17	-0.02

Table B-2 Food consumption impacts of expansion of US soybean biodiesel (figures are in %)

Food category	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	-0.02	0.00	-0.02	-0.01	0.00	0.00	0.00	-0.03	-0.03	0.00	-0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.03	-0.01	0.00
Wheat	-0.02	0.00	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.02	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.03	-0.02	-0.01
CrGrains	-0.02	0.00	-0.02	-0.02	-0.01	0.00	0.00	-0.03	-0.03	-0.01	-0.01	0.00	0.00	-0.01	-0.01	0.00	-0.03	-0.01	-0.01
Soybeans	-0.06	-0.04	-0.03	-0.06	0.00	0.00	0.00	-0.15	-0.07	-0.06	-0.05	-0.05	-0.03	0.00	-0.05	-0.01	-0.08	-0.02	-0.10
Oth_Oilseeds	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.03	0.00	0.02	-0.01	0.04	0.01	0.03	0.01	0.00	-0.01	-0.01	0.02
Sugar_Crop	-0.03	0.00	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.03	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.02	-0.01	0.00
OthAgri	-0.03	0.00	-0.02	-0.02	0.00	0.00	0.00	-0.03	-0.03	0.00	-0.01	0.00	0.00	-0.01	-0.01	0.00	-0.03	-0.01	0.00
Dairy_Farms	0.10	0.00	-0.01	0.06	0.00	0.01	0.01	-0.03	-0.02	0.01	0.00	0.02	0.01	-0.01	0.00	0.00	-0.03	-0.03	0.00
Ruminant	0.05	0.00	-0.01	0.06	0.00	0.00	0.02	0.00	-0.02	0.01	-0.01	0.01	0.02	-0.01	0.00	-0.01	-0.03	-0.02	0.00
NonRuminant	0.13	0.01	0.01	0.10	0.01	0.01	0.01	0.00	0.00	0.02	0.01	0.02	0.01	-0.01	0.00	0.00	-0.03	-0.02	0.00
Proc_Dairy	0.02	0.00	0.00	0.01	0.00	0.00	0.01	-0.01	-0.01	0.00	0.00	0.01	0.00	-0.02	0.00	0.00	-0.03	-0.02	0.00
Proc_Rum	0.01	0.00	0.00	0.03	0.00	0.00	0.01	0.00	-0.01	0.01	-0.01	0.01	0.00	-0.02	0.00	-0.01	-0.03	-0.02	0.00
proc_NonRum	0.04	0.00	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	-0.01	0.00	0.00	-0.03	-0.02	0.00
Bev_Sug	-0.02	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	-0.02	0.00	-0.01	-0.03	-0.02	0.00
Proc_Rice	-0.01	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.03	-0.01	0.00
Proc_Food	-0.04	0.00	0.00	-0.02	0.00	0.00	0.00	-0.01	-0.01	0.00	-0.01	0.00	0.00	-0.02	0.00	-0.01	-0.03	-0.02	0.00
Vol_Soy1	-4.72	-0.43	-0.32	-2.72	-0.69	-0.22	-0.10	-1.30	-0.37	-0.33	-0.29	-0.41	-0.18	-0.25	-0.51	-0.51	-0.57	-0.32	-0.76
Vol_Oth1	-1.27	-0.12	-0.09	-0.91	-0.17	-0.11	-0.03	-0.38	-0.13	-0.10	-0.08	-0.10	-0.05	-0.08	-0.09	-0.16	-0.15	-0.09	-0.14
Food consumption index	-0.03	0.00	-0.01	-0.02	0.00	0.00	0.00	-0.04	-0.02	0.00	-0.01	0.00	0.00	-0.02	-0.01	-0.01	-0.04	-0.02	0.00

Table B-3 Food consumption impacts of expansion of sugar cane ethanol in Brazil (figures are in %)

Food category	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	-0.01	-0.01	-0.41	-0.01	0.00	-0.01	0.00	-0.03	-0.06	0.00	-0.02	0.00	0.00	-0.04	-0.01	-0.01	-0.06	-0.02	-0.01
Wheat	0.00	-0.02	-0.31	-0.02	0.00	-0.01	0.00	-0.02	-0.03	0.00	-0.02	0.00	0.00	-0.04	-0.01	-0.01	-0.06	-0.03	-0.01
CrGrains	0.00	-0.02	-0.37	-0.01	0.00	-0.01	0.00	-0.03	-0.04	-0.01	-0.02	-0.01	0.00	-0.04	-0.01	-0.01	-0.06	-0.02	-0.01
Soybeans	-0.01	-0.08	-0.38	-0.02	0.00	-0.01	0.00	-0.06	-0.06	-0.04	-0.03	-0.05	-0.01	-0.05	-0.03	-0.04	-0.13	-0.03	-0.02
Oth_Oilseeds	-0.01	-0.02	-0.38	-0.02	0.00	-0.01	0.00	-0.03	-0.04	-0.01	-0.02	-0.02	0.00	-0.05	-0.02	-0.02	-0.07	-0.03	-0.02
Sugar_Crop	-0.01	-0.01	-1.40	-0.02	0.00	-0.01	0.00	-0.03	-0.04	0.01	-0.02	0.00	0.00	-0.04	-0.01	-0.01	-0.05	-0.02	-0.01
OthAgri	-0.01	-0.02	-0.45	-0.02	0.00	-0.01	0.00	-0.03	-0.04	-0.01	-0.02	-0.01	0.00	-0.04	-0.02	-0.01	-0.06	-0.03	-0.01
Dairy_Farms	-0.02	-0.02	-0.49	-0.02	-0.01	-0.02	0.00	-0.04	-0.05	0.00	-0.02	-0.02	0.00	-0.05	-0.02	-0.04	-0.08	-0.06	-0.01
Ruminant	-0.02	-0.02	-0.48	-0.02	-0.01	-0.02	0.00	-0.02	-0.05	0.00	-0.02	-0.01	0.00	-0.05	-0.02	-0.04	-0.08	-0.06	-0.01
NonRuminant	-0.01	-0.01	-0.39	-0.01	-0.01	-0.01	0.01	-0.01	-0.03	0.00	-0.01	0.01	0.00	-0.05	-0.01	-0.03	-0.07	-0.05	0.00
Proc_Dairy	0.00	0.00	-0.41	-0.01	0.00	-0.01	0.01	-0.02	-0.03	0.00	-0.01	0.01	0.00	-0.04	-0.01	-0.02	-0.07	-0.05	0.00
Proc_Rum	-0.01	-0.02	-0.42	-0.01	0.00	-0.01	0.01	-0.01	-0.03	0.00	-0.01	-0.01	0.00	-0.05	-0.01	-0.02	-0.08	-0.05	0.00
proc_NonRum	0.00	-0.01	-0.39	-0.01	-0.01	-0.01	0.01	-0.01	-0.02	0.00	-0.01	0.00	0.00	-0.07	-0.02	-0.02	-0.09	-0.06	0.00
Bev_Sug	0.00	-0.01	-0.51	-0.01	0.00	0.00	-0.01	-0.02	-0.02	0.00	-0.01	0.01	0.00	-0.07	-0.01	-0.02	-0.07	-0.04	0.00
Proc_Rice	0.00	0.00	-0.34	-0.01	0.00	0.00	0.00	-0.01	-0.03	0.00	-0.01	0.00	0.00	-0.04	-0.01	-0.01	-0.05	-0.02	0.00
Proc_Food	0.00	-0.01	-0.37	-0.01	0.00	-0.01	0.00	-0.02	-0.02	0.00	-0.01	0.00	0.00	-0.04	-0.01	-0.02	-0.06	-0.03	0.00
Vol_Soy1	-0.05	-0.12	-0.42	-0.03	-0.03	-0.02	-0.01	-0.02	-0.05	-0.11	-0.04	-0.03	-0.05	-0.06	-0.06	-0.14	-0.14	-0.07	-0.14
Vol_Oth1	0.02	0.01	-0.31	0.00	0.02	0.01	0.01	-0.01	-0.02	0.01	0.00	0.01	0.01	-0.03	0.00	0.00	-0.05	-0.03	0.01
Food consumption index	0.00	-0.01	**-0.41**	-0.01	0.00	-0.01	0.00	-0.02	-0.03	0.00	-0.01	0.00	0.00	-0.05	-0.01	-0.02	-0.07	-0.03	0.00

Table B-4 Food prices impacts of expansion of US corn ethanol (figures are in %)

Food category	Global export price	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	0.96	2.13	0.19	0.53	0.34	0.30	0.33	0.37	0.98	0.69	0.49	0.30	0.43	0.20	0.08	0.18	-0.13	0.16	0.27	0.56
Wheat	0.80	1.64	0.24	0.43	0.71	0.50	0.29	0.24	0.63	0.64	0.56	0.43	0.18	0.27	0.17	0.18	0.39	0.18	0.28	0.72
CrGrains	3.13	7.06	0.26	0.56	0.30	0.83	0.42	0.35	0.95	0.71	0.74	0.26	0.66	0.30	0.05	0.23	0.48	0.10	0.17	1.02
Soybeans	1.47	2.64	0.37	0.50	0.93	0.52	0.44	0.38	1.00	0.60	0.82	0.35	0.76	0.31	0.25	0.58	0.39	0.41	0.41	1.01
Oth_Oilseeds	0.58	2.00	0.22	0.45	0.69	0.46	0.46	0.36	0.65	0.47	0.86	0.28	0.55	0.31	0.20	0.31	0.53	0.15	0.27	0.60
Sugar_Crop	0.22	3.56	0.19	0.29	0.79	0.31	0.28	0.32	0.78	0.57	0.23	0.26	0.33	0.26	0.03	0.10	0.28	0.01	0.06	0.54
OthAgri	0.65	2.54	0.28	0.53	0.75	0.29	0.36	0.33	0.87	0.74	0.53	0.42	0.55	0.30	0.04	0.24	0.32	0.14	0.24	0.57
Dairy_Farms	0.13	0.79	0.09	0.28	0.34	0.28	0.25	0.33	1.48	0.32	0.37	0.06	0.28	0.18	-0.09	0.14	0.07	-0.02	-0.04	0.15
Ruminant	0.14	0.80	0.07	0.27	0.35	0.45	0.21	0.25	0.30	0.26	0.32	0.19	0.31	0.17	-0.10	0.09	0.08	-0.01	-0.06	0.16
NonRuminant	0.16	1.17	-0.05	0.02	0.22	0.27	0.09	0.07	0.11	0.09	0.49	0.02	0.05	0.06	-0.09	0.01	-0.05	-0.03	-0.12	-0.03
Proc_Dairy	-0.04	0.38	-0.08	0.05	0.12	-0.01	0.02	0.00	0.44	0.05	0.08	0.03	0.00	0.06	-0.21	0.00	-0.11	-0.15	-0.18	0.03
Proc_Rum	0.03	0.41	-0.06	0.11	0.11	0.17	0.04	-0.04	0.11	0.03	0.30	0.12	0.05	0.04	-0.16	-0.03	-0.09	-0.15	-0.14	0.03
proc_NonRum	0.02	0.54	-0.08	0.00	0.09	-0.03	0.05	-0.04	0.11	-0.02	0.31	-0.06	0.03	0.03	-0.20	-0.04	-0.09	-0.15	-0.15	0.00
Bev_Sug	-0.02	0.35	-0.05	0.02	0.04	-0.05	-0.01	0.04	0.08	-0.05	0.02	0.01	-0.01	0.02	-0.13	0.01	-0.09	-0.18	-0.14	-0.01
Proc_Rice	0.17	0.32	-0.06	0.24	2.01	0.21	0.07	-0.10	0.55	0.36	0.46	0.23	0.31	0.11	0.05	-0.05	-0.09	0.04	0.08	0.01
Proc_Food	0.01	0.32	-0.06	0.08	0.07	0.06	0.10	0.04	0.25	0.00	0.23	0.03	0.07	0.10	-0.11	-0.02	-0.12	-0.09	-0.13	-0.03
Vol_Soy1	0.15	0.82	-0.10	0.10	0.56	0.73	-0.34	-0.04	-0.21	0.08	1.24	0.47	-0.04	0.38	-0.26	-0.03	-0.02	-0.21	0.02	0.15
Vol_Oth1	-0.16	-0.39	-0.18	-0.17	-0.20	-0.24	-0.39	-0.08	0.09	-0.03	0.88	-0.13	-0.13	-0.11	-0.29	-0.19	-0.21	-0.30	-0.21	-0.16

Table B-5 Food prices impacts of expansion of US soybean biodiesel (figures are in %)

Food category	Global export price	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	0.11	0.27	0.00	0.16	0.01	0.02	-0.01	-0.01	0.13	0.18	0.04	0.03	0.01	-0.03	-0.02	0.00	-0.01	-0.01	0.01	0.03
Wheat	0.07	0.16	0.00	0.09	0.02	0.03	-0.01	-0.01	0.06	0.12	0.03	0.06	0.02	-0.02	-0.01	0.00	0.01	0.00	0.02	0.04
CrGrains	0.17	0.35	0.01	0.15	0.06	0.04	0.01	0.00	0.12	0.18	0.05	0.03	0.06	0.02	-0.02	0.00	0.01	-0.01	0.00	0.06
Soybeans	0.73	1.30	0.10	0.22	0.36	-0.09	-0.03	-0.09	0.44	0.39	-0.19	0.36	0.09	0.67	-0.09	0.34	0.17	0.18	0.26	0.34
Oth_Oilseeds	-0.15	-0.47	-0.08	-0.03	-0.20	-0.17	-0.04	-0.24	-0.19	0.01	-0.23	0.02	-0.56	-0.20	-0.29	-0.13	-0.31	-0.10	-0.09	-0.13
Sugar_Crop	0.01	0.44	0.00	0.11	0.01	0.02	-0.01	-0.01	0.09	0.16	0.02	0.03	0.00	-0.02	-0.02	-0.01	-0.01	-0.02	0.00	0.02
OthAgri	0.07	0.34	0.01	0.15	0.06	0.01	0.00	0.00	0.11	0.15	0.05	0.05	0.03	-0.01	-0.02	0.00	0.00	-0.01	0.01	0.03
Dairy_Farms	-0.02	-0.27	-0.02	0.06	-0.20	0.00	-0.05	0.00	0.10	0.06	-0.02	-0.01	-0.08	-0.04	-0.03	-0.01	-0.02	-0.03	-0.03	-0.02
Ruminant	-0.03	-0.16	-0.02	0.05	-0.20	-0.01	-0.02	-0.07	-0.05	0.06	-0.02	0.00	-0.02	-0.10	-0.03	-0.02	-0.01	-0.04	-0.04	-0.01
NonRuminant	-0.10	-0.36	-0.03	0.00	-0.38	-0.02	-0.07	-0.02	-0.05	0.00	-0.04	-0.06	-0.07	-0.05	-0.04	-0.02	-0.01	-0.04	-0.07	-0.01
Proc_Dairy	-0.01	-0.07	-0.01	0.03	-0.07	-0.01	-0.01	0.00	0.01	0.03	0.00	0.00	-0.01	0.00	-0.02	-0.01	-0.01	-0.02	-0.02	-0.01
Proc_Rum	-0.02	-0.06	-0.01	0.03	-0.12	-0.01	-0.01	0.00	-0.01	0.03	-0.02	0.00	-0.01	-0.01	-0.03	-0.01	-0.01	-0.03	-0.03	-0.01
proc_NonRum	-0.03	-0.13	-0.01	0.01	-0.12	-0.01	-0.05	-0.01	-0.01	0.00	-0.03	-0.02	-0.04	0.00	-0.02	-0.01	-0.01	-0.04	-0.04	-0.01
Bev_Sug	0.00	0.04	-0.01	0.02	0.02	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00	-0.01	-0.02	0.00	-0.01	-0.02	-0.02	0.00
Proc_Rice	0.01	0.03	-0.01	0.09	0.15	0.01	0.00	-0.01	0.07	0.08	0.04	0.03	0.01	-0.02	-0.01	-0.01	-0.01	-0.01	0.00	0.00
Proc_Food	0.01	0.08	-0.01	0.04	0.03	0.01	0.03	0.00	0.02	0.03	0.02	0.01	0.00	0.00	-0.02	0.00	-0.01	-0.02	-0.01	-0.01
Vol_Soy1	2.96	15.49	1.14	1.58	5.80	1.69	1.23	0.60	4.22	1.61	1.19	2.21	2.43	0.47	0.94	1.35	1.09	1.42	1.00	1.52
Vol_Oth1	0.69	5.74	0.38	0.50	2.77	0.42	0.67	0.29	1.47	0.52	0.33	0.58	0.60	0.49	0.32	0.40	0.43	0.47	0.54	0.44

Table B-6 Food prices impacts of expansion of sugar cane ethanol in Brazil (figures are in %)

Food category	Global export price	USA	EU27	BRAZIL	CAN	JAPAN	CHIHKG	INDIA	C_C_Amer	S_o_Amer	E_Asia	Mala_Indo	R_SE_Asia	R_S_Asia	Russia	Oth_CEE_CIS	Oth_Europe	MEAS_NAfr	S_S_AFR	Oceania
Paddy_Rice	0.09	0.10	0.06	1.38	0.04	0.03	0.05	0.07	0.09	0.25	0.05	0.07	0.07	0.04	0.04	0.04	-0.02	0.05	0.06	0.07
Wheat	0.09	0.09	0.07	0.73	0.08	0.04	0.04	0.04	0.06	0.14	0.05	0.09	0.02	0.05	0.05	0.05	0.08	0.05	0.05	0.08
CrGrains	0.15	0.09	0.10	1.25	0.06	0.04	0.05	0.06	0.10	0.17	0.06	0.08	0.08	0.04	0.04	0.06	0.07	0.02	0.05	0.09
Soybeans	0.49	0.19	0.22	1.10	0.12	0.06	0.09	0.10	0.14	0.28	0.15	0.17	0.23	0.17	0.12	0.15	0.59	0.24	0.10	0.13
Oth_Oilseeds	0.20	0.16	0.09	1.12	0.11	0.06	0.10	0.08	0.09	0.16	0.17	0.08	0.13	0.08	0.08	0.09	0.27	0.07	0.08	0.11
Sugar_Crop	0.06	0.14	0.07	6.23	0.11	0.03	0.04	0.07	0.10	0.17	0.03	0.07	0.06	0.06	0.06	0.04	0.07	0.02	0.03	0.07
OthAgri	0.15	0.12	0.10	1.44	0.09	0.03	0.06	0.07	0.11	0.19	0.06	0.09	0.09	0.06	0.03	0.06	0.09	0.05	0.07	0.08
Dairy_Farms	0.05	0.03	0.05	1.04	0.04	0.02	0.05	0.06	0.09	0.13	0.03	0.05	0.07	0.04	0.01	0.04	0.04	0.02	0.02	0.03
Ruminant	0.04	0.03	0.04	1.01	0.04	0.02	0.04	0.05	0.03	0.12	0.03	0.04	0.09	0.04	0.01	0.03	0.04	0.02	0.01	0.04
NonRuminant	0.02	0.01	0.01	0.71	0.02	0.00	0.02	0.01	0.01	0.06	0.04	0.01	0.01	0.01	0.00	0.01	0.02	0.00	0.00	0.00
Proc_Dairy	0.00	0.01	0.00	0.76	0.01	-0.01	0.01	0.00	0.02	0.06	0.01	0.02	0.01	0.01	-0.03	0.01	-0.01	-0.01	-0.02	0.01
Proc_Rum	0.07	0.01	0.00	0.80	0.01	0.00	0.02	0.00	0.00	0.06	0.02	0.03	0.03	0.01	-0.01	0.00	0.00	-0.01	-0.01	0.01
proc_NonRum	0.07	0.00	0.00	0.68	0.00	-0.01	0.01	0.01	0.00	0.04	0.02	-0.01	0.01	0.00	-0.02	0.00	0.01	-0.02	-0.01	0.00
Bev_Sug	0.05	0.00	0.00	1.27	0.00	-0.01	0.00	0.03	0.01	0.03	0.00	0.01	0.00	0.01	0.01	0.01	0.00	-0.02	-0.01	0.00
Proc_Rice	0.03	0.00	0.00	0.97	0.08	0.02	0.01	-0.01	0.04	0.12	0.05	0.06	0.05	0.02	0.03	0.00	0.01	0.02	0.03	0.00
Proc_Food	0.01	0.00	0.00	0.75	0.00	-0.01	0.02	0.01	0.02	0.04	0.02	0.01	0.02	0.03	0.00	0.01	-0.01	0.00	-0.01	0.00
Vol_Soy1	0.33	0.07	0.14	0.92	0.03	0.07	0.01	0.02	-0.02	0.15	0.37	0.16	0.12	0.54	0.01	0.06	0.28	0.07	0.09	0.28
Vol_Oth1	-0.02	-0.05	-0.04	0.54	-0.03	-0.04	-0.10	-0.02	0.01	0.03	-0.01	-0.03	-0.03	-0.03	-0.05	-0.04	-0.04	-0.06	-0.04	-0.04

Table B-7 Sensitivity of land cover changes due to expansion of US coarse grains ethanol with respect to changes in food consumption, ha

Region	Food consumption is allowed to adjust as prices change in the wake of corn ethanol expansion (central)			Food consumption is fixed in developing countries			Food consumption is fixed globally		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-352,528	1,002,512	-649,984	-353,312	1,019,808	-666,528	-395,152	1,038,784	-643,664
2 EU27	-81,184	127,848	-46,640	-95,120	146,576	-51,496	-119,456	171,744	-52,284
3 BRAZIL	-3,648	88,596	-84,928	-11,552	98,560	-87,040	-13,472	107,212	-93,664
4 CAN	-115,112	172,312	-57,192	-129,752	191,084	-61,330	-153,792	214,376	-60,590
5 JAPAN	-3,076	3,530	-452	-3,286	3,758	-473	-3,994	4,335	-340
6 CHIHKG	17,648	55,104	-72,736	16,208	63,424	-79,616	18,480	67,616	-86,112
7 INDIA	-1,918	4,768	-2,835	-1,976	7,696	-5,684	-2,560	8,816	-6,272
8 C_C_Amer	32,328	20,992	-53,320	25,492	23,060	-48,552	25,800	24,968	-50,776
9 S_o_Amer	81,560	65,520	-147,104	56,904	68,524	-125,392	60,736	74,088	-134,816
10 E_Asia	3,984	806	-4,784	3,776	876	-4,648	3,982	897	-4,872
11 Mala_Indo	7,388	-3,840	-3,510	6,768	-3,192	-3,559	7,172	-3,328	-3,827
12 R_SE_Asia	2,496	2,640	-5,134	2,384	3,376	-5,779	2,528	3,672	-6,213
13 R_S_Asia	-1,756	23,424	-21,668	-2,490	28,416	-25,932	-2,909	31,752	-28,856
14 Russia	189,520	8,752	-198,216	200,576	12,776	-213,328	146,576	21,128	-167,736
15 Oth_CEE_CIS	-21,244	105,112	-83,840	-34,480	125,352	-90,880	-39,124	140,288	-101,184
16 Oth_Europe	-86	1,649	-1,564	-126	1,892	-1,761	-516	1,912	-1,397
17 MEAS_NAfr	-80	86,008	-85,936	-2,981	121,316	-118,368	-3,069	130,532	-127,456
18 S_S_AFR	-44,144	274,400	-230,080	-148,368	329,072	-180,736	-159,008	361,280	-202,240
19 Oceania	-785	86,128	-85,344	-1,369	93,136	-91,840	-2,036	101,368	-99,392
Total	-290,637	2,126,261	-1,835,267	-472,705	2,335,510	-1,862,942	-629,814	2,501,440	-1,871,692
ha/1000 gall	-0.03	0.18	-0.16	-0.04	0.20	-0.16	-0.05	0.22	-0.16

Table B-8 Sensitivity of land cover changes due to expansion of US soy biodiesel with respect to changes in food consumption, ha

Region	Food consumption is allowed to adjust as prices change in the wake of soy biodiesel expansion			Food consumption is fixed in developing countries			Food consumption is fixed globally		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-43,620	97,418	-53,798	-44,048	99,680	-55,680	-43,536	110,704	-67,136
2 EU27	1,352	2,620	-3,972	80	4,400	-4,464	-1,088	6,376	-5,264
3 BRAZIL	-1,923	20,506	-18,583	-2,992	23,252	-20,304	-3,584	26,368	-22,784
4 CAN	9,203	-12,489	3,287	8,072	-11,056	2,994	5,928	-7,228	1,288
5 JAPAN	-13	72	-58	-24	86	-60	-34	101	-66
6 CHIHKG	3,446	-1,501	-1,945	3,856	-1,776	-2,080	4,368	-1,760	-2,656
7 INDIA	1,659	-2,509	849	1,896	-2,320	408	1,934	-2,336	391
8 C_C_Amer	4,583	2,676	-7,260	4,140	3,032	-7,168	4,768	3,448	-8,240
9 S_o_Amer	6,279	17,006	-23,284	4,576	18,820	-23,392	5,136	20,844	-25,984
10 E_Asia	264	-11	-253	324	-2	-320	352	-3	-344
11 Mala_Indo	141	115	-256	-84	376	-277	-180	496	-318
12 R_SE_Asia	889	-532	-357	968	-472	-479	992	-472	-537
13 R_S_Asia	418	-2,322	1,904	420	-664	248	417	-512	88
14 Russia	15,999	-3,814	-12,187	16,864	-3,568	-13,344	14,000	-3,120	-10,840
15 Oth_CEE_CIS	919	2,071	-2,990	28	3,816	-3,872	-284	5,000	-4,704
16 Oth_Europe	126	14	-140	128	33	-161	118	38	-160
17 MEAS_NAfr	58	2,430	-2,488	-184	5,604	-5,456	-192	6,464	-6,272
18 S_S_AFR	1,253	14,330	-15,583	-7,840	19,808	-11,840	-8,752	23,088	-14,400
19 Oceania	1,146	7,108	-8,254	1,121	7,824	-8,992	1,224	9,172	-10,496
Total	2,179	143,189	-145,369	-12,699	166,873	-154,240	-18,414	196,668	-178,434
ha/1000 gall	0.00	0.18	-0.18	-0.02	0.21	-0.19	-0.02	0.24	-0.22

Table B-9 Sensitivity of land cover changes due to expansion of Brazilian sugar cane ethanol with respect to changes in food consumption, ha

Region	Food consumption is allowed to adjust as prices change in the wake of sugar cane ethanol expansion			Food consumption is fixed in developing countries			Food consumption is fixed globally		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-5,344	37,296	-31,904	-6,080	44,608	-38,560	-7,376	47,136	-39,760
2 EU27	-33,696	38,080	-4,404	-39,488	45,368	-5,924	-45,728	50,760	-5,036
3 BRAZIL	-28,720	221,760	-193,040	-70,960	230,344	-159,376	-71,312	231,696	-160,368
4 CAN	-24,664	32,132	-7,484	-29,880	38,872	-8,992	-32,504	41,444	-8,948
5 JAPAN	-438	454	-18	-514	536	-24	-562	580	-17
6 CHIHKG	-480	8,496	-8,000	-1,008	10,960	-9,952	-384	11,232	-10,848
7 INDIA	-660	1,504	-831	-1,064	2,352	-1,293	-1,092	2,480	-1,369
8 C_C_Amer	5,472	2,312	-7,776	5,580	2,912	-8,496	6,084	3,104	-9,192
9 S_o_Amer	-760	14,496	-13,712	-7,672	16,504	-8,832	-6,896	17,336	-10,448
10 E_Asia	316	68	-384	378	85	-456	410	84	-488
11 Mala_Indo	308	200	-501	172	376	-544	260	336	-585
12 R_SE_Asia	-360	272	87	-472	412	54	-376	404	-23
13 R_S_Asia	-478	4,992	-4,516	-722	6,172	-5,452	-773	6,628	-5,860
14 Russia	23,488	4,392	-27,864	26,816	5,528	-32,368	14,528	7,176	-21,704
15 Oth_CEE_CIS	-5,764	22,472	-16,672	-9,360	28,704	-19,328	-10,088	31,224	-21,184
16 Oth_Europe	-44	303	-258	-56	376	-320	-146	366	-226
17 MEAS_NAfr	-263	15,964	-15,712	-843	24,268	-23,424	-852	25,712	-24,864
18 S_S_AFR	-23,744	57,648	-33,856	-46,880	74,496	-27,520	-48,400	79,616	-31,168
19 Oceania	-1,066	8,852	-7,744	-1,268	11,140	-9,888	-1,345	12,248	-10,880
Total	-96,897	471,693	-374,589	-183,322	544,012	-360,695	-206,552	569,561	-362,969
ha/1000 gall	-0.03	0.16	-0.12	-0.06	0.18	-0.12	-0.07	0.19	-0.12

Appendix C

Table C-1 Sensitivity of land cover changes due to expansion of US coarse grains ethanol with respect to yield-to-price elasticity, ha

Region	yield-to-price elasticity 0.25 (central)			yield-to-price elasticity 0.1			yield-to-price elasticity 0.05		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-352,528	1,002,512	-649,984	-379,910	1,142,657	-762,747	-389,648	1,203,138	-813,490
2 EU27	-81,184	127,848	-46,640	-131,755	198,512	-66,759	-158,037	235,147	-77,110
3 BRAZIL	-3,648	88,596	-84,928	-9,547	125,672	-116,130	-12,271	144,099	-131,827
4 CAN	-115,112	172,312	-57,192	-172,214	248,817	-76,604	-199,497	285,410	-85,914
5 JAPAN	-3,076	3,530	-452	-5,183	5,679	-496	-6,295	6,808	-513
6 CHIHKG	17,648	55,104	-72,736	25,226	94,342	-119,568	29,143	116,507	-145,651
7 INDIA	-1,918	4,768	-2,835	-10,932	21,009	-10,077	-17,119	31,840	-14,721
8 C_C_Amer	32,328	20,992	-53,320	43,989	31,165	-75,153	50,161	36,200	-86,361
9 S_o_Amer	81,560	65,520	-147,104	104,182	90,201	-194,383	115,928	102,283	-218,208
10 E_Asia	3,984	806	-4,784	4,631	1,205	-5,836	4,927	1,417	-6,344
11 Mala_Indo	7,388	-3,840	-3,510	7,801	-2,650	-5,151	7,932	-1,872	-6,060
12 R_SE_Asia	2,496	2,640	-5,134	1,083	6,050	-7,134	290	7,909	-8,198
13 R_S_Asia	-1,756	23,424	-21,668	-4,350	45,457	-41,107	-5,850	57,903	-52,053
14 Russia	189,520	8,752	-198,216	227,740	22,610	-250,350	246,978	30,528	-277,506
15 Oth_CEE_CIS	-21,244	105,112	-83,840	-35,898	159,684	-123,789	-43,658	188,326	-144,671
16 Oth_Europe	-86	1,649	-1,564	-185	2,379	-2,194	-231	2,753	-2,523
17 MEAS_NAfr	-80	86,008	-85,936	-446	125,287	-124,842	-634	145,505	-144,872
18 S_S_AFR	-44,144	274,400	-230,080	-91,221	410,618	-319,383	-116,099	482,273	-366,158
19 Oceania	-785	86,128	-85,344	-1,081	120,179	-119,098	-1,172	137,081	-135,909
Total	-290,637	2,126,261	-1,835,267	-428,068	2,848,873	-2,420,799	-495,152	3,213,255	-2,718,089
ha/1000 gall	-0.03	0.18	-0.16	-0.04	0.25	-0.21	-0.04	0.28	-0.23

Table C-2 Sensitivity of land cover changes due to expansion of US soy biodiesel with respect to yield-to-price elasticity,ha

Region	yield-to-price elasticity 0.25 (central)			yield-to-price elasticity 0.1			yield-to-price elasticity 0.05		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-43,620	97,418	-53,798	-47,576	112,779	-65,202	-49,119	119,376	-70,257
2 EU27	1,352	2,620	-3,972	-2,216	7,650	-5,434	-4,147	10,354	-6,207
3 BRAZIL	-1,923	20,506	-18,583	-3,462	25,177	-21,714	-4,104	27,305	-23,201
4 CAN	9,203	-12,489	3,287	4,512	-6,167	1,655	2,239	-3,107	868
5 JAPAN	-13	72	-58	-149	213	-64	-224	290	-66
6 CHIHKG	3,446	-1,501	-1,945	4,054	319	-4,373	4,357	1,484	-5,840
7 INDIA	1,659	-2,509	849	1,725	-2,443	717	1,649	-2,237	588
8 C_C_Amer	4,583	2,676	-7,260	5,446	3,585	-9,031	5,894	4,031	-9,925
9 S_o_Amer	6,279	17,006	-23,284	7,844	19,921	-27,764	8,661	21,240	-29,900
10 E_Asia	264	-11	-253	314	17	-331	335	32	-367
11 Mala_Indo	141	115	-256	132	241	-373	124	313	-437
12 R_SE_Asia	889	-532	-357	874	-379	-496	847	-280	-568
13 R_S_Asia	418	-2,322	1,904	320	-1,318	998	251	-687	436
14 Russia	15,999	-3,814	-12,187	19,115	-3,350	-15,761	20,640	-2,996	-17,644
15 Oth_CEE_CIS	919	2,071	-2,990	65	5,545	-5,610	-423	7,453	-7,031
16 Oth_Europe	126	14	-140	125	61	-187	125	86	-211
17 MEAS_NAfr	58	2,430	-2,488	37	5,094	-5,130	24	6,522	-6,546
18 S_S_AFR	1,253	14,330	-15,583	-2,137	24,011	-21,868	-3,961	29,186	-25,224
19 Oceania	1,146	7,108	-8,254	1,123	9,616	-10,738	1,113	10,883	-11,996
Total	2,179	143,189	-145,369	-9,855	200,572	-190,705	-15,720	229,247	-213,526
ha/1000 gall	0.00	0.18	-0.18	-0.01	0.25	-0.23	-0.02	0.28	-0.26

Table C-3 Sensitivity of land cover changes due to expansion of Brazilian sugar cane ethanol with respect to yield-to-price elasticity, ha

Region	yield-to-price elasticity 0.25 (central)			yield-to-price elasticity 0.1			yield-to-price elasticity 0.05		
	forest	cropland	pasture	forest	cropland	pasture	forest	cropland	pasture
1 USA	-5,344	37,296	-31,904	-6,624	51,552	-44,912	-7,200	58,720	-51,488
2 EU27	-33,696	38,080	-4,404	-44,672	52,808	-8,132	-50,144	60,168	-10,036
3 BRAZIL	-28,720	221,760	-193,040	-37,824	243,612	-205,808	-41,296	252,508	-211,216
4 CAN	-24,664	32,132	-7,484	-33,072	43,372	-10,298	-37,288	49,004	-11,720
5 JAPAN	-438	454	-18	-712	734	-24	-862	888	-27
6 CHIHKG	-480	8,496	-8,000	800	14,448	-15,200	1,456	17,840	-19,296
7 INDIA	-660	1,504	-831	-2,268	4,384	-2,107	-3,352	6,272	-2,915
8 C_C_Amer	5,472	2,312	-7,776	7,512	3,620	-11,128	8,556	4,300	-12,880
9 S_o_Amer	-760	14,496	-13,712	2,648	19,252	-21,920	4,472	21,536	-26,000
10 E_Asia	316	68	-384	416	116	-536	464	143	-608
11 Mala_Indo	308	200	-501	284	512	-781	268	680	-933
12 R_SE_Asia	-360	272	87	-552	792	-220	-688	1,072	-387
13 R_S_Asia	-478	4,992	-4,516	-927	8,740	-7,820	-1,182	10,836	-9,656
14 Russia	23,488	4,392	-27,864	28,992	7,440	-36,448	31,856	9,040	-40,936
15 Oth_CEE_CIS	-5,764	22,472	-16,672	-8,496	32,464	-23,936	-9,916	37,616	-27,680
16 Oth_Europe	-44	303	-258	-60	433	-374	-64	498	-433
17 MEAS_NAfr	-263	15,964	-15,712	-336	23,080	-22,752	-373	26,732	-26,400
18 S_S_AFR	-23,744	57,648	-33,856	-32,752	82,544	-49,728	-37,344	95,440	-58,048
19 Oceania	-1,066	8,852	-7,744	-1,116	13,856	-12,768	-1,133	16,444	-15,328
Total	-96,897	471,693	-374,589	-128,759	603,758	-474,892	-143,770	669,736	-525,987
ha/1000 gall	-0.03	0.16	-0.12	-0.04	0.20	-0.16	-0.05	0.22	-0.18

Appendix D

Table D-1 Sensitivity of land cover changes due to expansion of US corn ethanol with respect to land transformation elasticity among crops, (hectares)

Region	Transformation Elasticity = -0.75			Transformation Elasticity = -0.5		
	forest	Cropland	pasture	forest	Cropland	Pasture
1 USA	-352,528	1,002,512	-649,984	-343,088	1,110,864	-767,696
2 EU27	-81,184	127,848	-46,640	-80,592	128,192	-47,624
3 BRAZIL	-3,648	88,596	-84,928	15,792	94,420	-110,160
4 CAN	-115,112	172,312	-57,192	-114,584	172,720	-58,128
5 JAPAN	-3,076	3,530	-452	-2,866	3,386	-519
6 CHIHKG	17,648	55,104	-72,736	17,488	55,216	-72,704
7 INDIA	-1,918	4,768	-2,835	-1,446	4,176	-2,779
8 C_C_Amer	32,328	20,992	-53,320	33,864	22,108	-55,976
9 S_o_Amer	81,560	65,520	-147,104	83,672	67,416	-151,088
10 E_Asia	3,984	806	-4,784	4,562	876	-5,448
11 Mala_Indo	7,388	-3,840	-3,510	7,836	-4,224	-3,588
12 R_SE_Asia	2,496	2,640	-5,134	3,216	2,048	-5,281
13 R_S_Asia	-1,756	23,424	-21,668	-1,516	22,936	-21,432
14 Russia	189,520	8,752	-198,216	195,712	7,600	-203,288
15 Oth_CEE_CIS	-21,244	105,112	-83,840	-21,484	107,232	-85,792
16 Oth_Europe	-86	1,649	-1,564	-218	1,796	-1,578
17 MEAS_NAfr	-80	86,008	-85,936	-72	89,168	-89,072
18 S_S_AFR	-44,144	274,400	-230,080	-40,000	269,424	-229,440
19 Oceania	-785	86,128	-85,344	-919	86,992	-86,144
Total	-290,637	2,126,261	-1,835,267	-244,643	2,242,346	-1,997,737
ha/1000 gall	-0.03	0.18	-0.16	-0.02	0.19	-0.17

Table D-2 Sensitivity of land cover changes due to expansion of US soybean biodiesel with respect to land transformation elasticity among crops, (hectares)

Region	Transformation Elasticity = -0.75			Transformation Elasticity = -0.5		
	Forest	Cropland	pasture	forest	cropland	pasture
1 USA	-43,620	97,418	-53,798	-38,928	98,288	-59,424
2 EU27	1,352	2,620	-3,972	2,000	1,936	-3,908
3 BRAZIL	-1,923	20,506	-18,583	816	24,296	-25,072
4 CAN	9,203	-12,489	3,287	10,432	-13,920	3,466
5 JAPAN	-13	72	-58	-8	67	-61
6 CHIHKG	3,446	-1,501	-1,945	3,232	-928	-2,208
7 INDIA	1,659	-2,509	849	1,570	-2,400	838
8 C_C_Amer	4,583	2,676	-7,260	4,760	2,532	-7,296
9 S_o_Amer	6,279	17,006	-23,284	6,168	18,916	-25,072
10 E_Asia	264	-11	-253	282	-12	-272
11 Mala_Indo	141	115	-256	248	8	-252
12 R_SE_Asia	889	-532	-357	896	-540	-365
13 R_S_Asia	418	-2,322	1,904	437	-2,396	1,952
14 Russia	15,999	-3,814	-12,187	16,032	-3,968	-12,128
15 Oth_CEE_CIS	919	2,071	-2,990	1,004	1,736	-2,784
16 Oth_Europe	126	14	-140	102	29	-135
17 MEAS_NAfr	58	2,430	-2,488	61	2,280	-2,384
18 S_S_AFR	1,253	14,330	-15,583	1,632	13,408	-14,912
19 Oceania	1,146	7,108	-8,254	1,200	6,444	-7,648
Total	2,179	143,189	-145,369	11,936	145,775	-157,664
ha/1000 gall	0.00	0.18	-0.18	0.01	0.18	-0.19

Table D-3 Sensitivity of land cover changes due to expansion of sugarcane ethanol in Brazil with respect to land transformation elasticity among crops, (hectares)

Region	Transformation Elasticity = -0.75			Transformation Elasticity = -0.5		
	forest	Cropland	pasture	forest	cropland	pasture
1 USA	-5,344	37,296	-31,904	-3,792	40,096	-36,320
2 EU27	-33,696	38,080	-4,404	-35,440	40,456	-5,036
3 BRAZIL	-28,720	221,760	-193,040	31,856	283,628	-315,504
4 CAN	-24,664	32,132	-7,484	-26,448	34,500	-8,062
5 JAPAN	-438	454	-18	-450	471	-21
6 CHIHKG	-480	8,496	-8,000	-320	8,896	-8,576
7 INDIA	-660	1,504	-831	-710	1,728	-1,002
8 C_C_Amer	5,472	2,312	-7,776	6,012	2,416	-8,432
9 S_o_Amer	-760	14,496	-13,712	-72	15,920	-15,872
10 E_Asia	316	68	-384	346	75	-416
11 Mala_Indo	308	200	-501	324	216	-530
12 R_SE_Asia	-360	272	87	-288	248	58
13 R_S_Asia	-478	4,992	-4,516	-507	5,460	-4,952
14 Russia	23,488	4,392	-27,864	24,688	4,624	-29,344
15 Oth_CEE_CIS	-5,764	22,472	-16,672	-6,072	23,888	-17,824
16 Oth_Europe	-44	303	-258	-36	317	-280
17 MEAS_NAfr	-263	15,964	-15,712	-256	16,800	-16,560
18 S_S_AFR	-23,744	57,648	-33,856	-24,912	60,784	-35,904
19 Oceania	-1,066	8,852	-7,744	-1,091	9,472	-8,416
Total	-96,897	471,693	-374,589	-37,167	549,994	-512,993
ha/1000 gall	-0.03	0.16	-0.12	-0.01	0.18	-0.17

Appendix E

Table E-1 Sensitivity of land cover changes due to expansion of US corn ethanol with respect to cropland pasture yield adjustment factor, (hectares)

Region	US=0.4 and Brazil=0.2			US=0.0 and Brazil=0.0		
	Forest	Cropland	pasture	Forest	Cropland	Pasture
1 USA	-352,528	1,002,512	-649,984	-539,888	889,792	-349,952
2 EU27	-81,184	127,848	-46,640	-84,144	130,112	-45,980
3 BRAZIL	-3,648	88,596	-84,928	-56,960	81,132	-24,128
4 CAN	-115,112	172,312	-57,192	-120,512	176,140	-55,626
5 JAPAN	-3,076	3,530	-452	-3,132	3,579	-446
6 CHIHKG	17,648	55,104	-72,736	16,400	55,744	-72,064
7 INDIA	-1,918	4,768	-2,835	-1,976	4,928	-2,917
8 C_C_Amer	32,328	20,992	-53,320	26,008	20,292	-46,320
9 S_o_Amer	81,560	65,520	-147,104	79,144	65,960	-145,104
10 E_Asia	3,984	806	-4,784	3,948	796	-4,744
11 Mala_Indo	7,388	-3,840	-3,510	7,444	-3,936	-3,498
12 R_SE_Asia	2,496	2,640	-5,134	2,496	2,580	-5,065
13 R_S_Asia	-1,756	23,424	-21,668	-1,814	24,056	-22,248
14 Russia	189,520	8,752	-198,216	191,664	8,784	-200,480
15 Oth_CEE_CIS	-21,244	105,112	-83,840	-21,796	106,744	-84,960
16 Oth_Europe	-86	1,649	-1,564	-98	1,664	-1,571
17 MEAS_NAfr	-80	86,008	-85,936	-146	87,036	-86,928
18 S_S_AFR	-44,144	274,400	-230,080	-47,776	278,480	-230,656
19 Oceania	-785	86,128	-85,344	-1,473	85,576	-84,032
Total	-290,637	2,126,261	-1,835,267	-552,610	2,019,458	-1,466,719
ha/1000 gall	-0.03	0.18	-0.16	-0.05	0.17	-0.13

Table E-2 Sensitivity of land cover changes due to expansion of US soybean biodiesel with respect to cropland pasture yield adjustment factor, (hectares)

Region	US=0.4 and Brazil=0.2			US=0.0 and Brazil=0.0		
	Forest	Cropland	pasture	forest	cropland	pasture
1 USA	-43,620	97,418	-53,798	-64,560	84,320	-19,808
2 EU27	1,352	2,620	-3,972	960	2,864	-3,912
3 BRAZIL	-1,923	20,506	-18,583	-12,832	18,848	-5,968
4 CAN	9,203	-12,489	3,287	8,568	-12,000	3,434
5 JAPAN	-13	72	-58	-20	77	-58
6 CHIHKG	3,446	-1,501	-1,945	3,296	-1,392	-1,888
7 INDIA	1,659	-2,509	849	1,652	-2,512	838
8 C_C_Amer	4,583	2,676	-7,260	3,916	2,608	-6,512
9 S_o_Amer	6,279	17,006	-23,284	5,952	17,072	-22,976
10 E_Asia	264	-11	-253	258	-12	-240
11 Mala_Indo	141	115	-256	144	96	-254
12 R_SE_Asia	889	-532	-357	888	-528	-347
13 R_S_Asia	418	-2,322	1,904	410	-2,244	1,828
14 Russia	15,999	-3,814	-12,187	16,240	-3,816	-12,416
15 Oth_CEE_CIS	919	2,071	-2,990	844	2,280	-3,136
16 Oth_Europe	126	14	-140	114	16	-141
17 MEAS_NAfr	58	2,430	-2,488	50	2,552	-2,608
18 S_S_AFR	1,253	14,330	-15,583	816	14,864	-15,488
19 Oceania	1,146	7,108	-8,254	1,069	7,064	-8,192
Total	2,179	143,189	-145,369	-32,236	130,157	-97,844
ha/1000 gall	0.00	0.18	-0.18	-0.04	0.16	-0.12

Table E-3 Sensitivity of land cover changes due to expansion of sugarcane ethanol in Brazil with respect to cropland pasture yield adjustment factor, (hectares)

Region	US=0.4 and Brazil=0.2			US=0.0 and Brazil=0.0		
	forest	Cropland	pasture	forest	cropland	pasture
1 USA	-5,344	37,296	-31,904	-14,432	32,000	-17,600
2 EU27	-33,696	38,080	-4,404	-34,384	38,528	-4,180
3 BRAZIL	-28,720	221,760	-193,040	-108,944	209,080	-100,144
4 CAN	-24,664	32,132	-7,484	-25,216	32,668	-7,466
5 JAPAN	-438	454	-18	-444	461	-18
6 CHIHKG	-480	8,496	-8,000	-704	8,592	-7,936
7 INDIA	-660	1,504	-831	-670	1,536	-845
8 C_C_Amer	5,472	2,312	-7,776	5,212	2,296	-7,520
9 S_o_Amer	-760	14,496	-13,712	-1,984	14,484	-12,496
10 E_Asia	316	68	-384	320	68	-384
11 Mala_Indo	308	200	-501	324	192	-502
12 R_SE_Asia	-360	272	87	-400	252	136
13 R_S_Asia	-478	4,992	-4,516	-488	5,088	-4,604
14 Russia	23,488	4,392	-27,864	23,504	4,368	-27,888
15 Oth_CEE_CIS	-5,764	22,472	-16,672	-5,860	22,760	-16,896
16 Oth_Europe	-44	303	-258	-54	306	-257
17 MEAS_NAfr	-263	15,964	-15,712	-281	16,092	-15,824
18 S_S_AFR	-23,744	57,648	-33,856	-24,608	58,320	-33,728
19 Oceania	-1,066	8,852	-7,744	-1,147	8,816	-7,680
Total	-96,897	471,693	-374,589	-190,255	455,906	-265,832
ha/1000 gall	-0.03	0.16	-0.12	-0.06	0.15	-0.09