Global Biofuel Expansion and the Demand for Brazilian Land: Intensification versus Expansion

Amani Elobeid, Miguel Carriquiry, and Jacinto F. Fabiosa
Center for Agricultural and Rural Development, Iowa State University

Selected Paper prepared for presentation at the Agricultural and Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburg, Pennsylvania, July 24-26, 2011

Global Biofuel Expansion and the Demand for Brazilian Land: Intensification versus Expansion

Abstract

We use a spatially disaggregated model of Brazilian agriculture to assess the implications of global biofuel expansion on Brazilian land usage at the regional level. This Brazilian model is part of the FAPRI agricultural modeling system, a multimarket, multi-commodity international agricultural model, used to quantify the emergence of biofuels and to analyze the impact of biofuel expansion and policies on both Brazilian and world agriculture. We evaluate two scenarios in which we introduce a 25% exogenous increase in the global demand for ethanol and one scenario in which we increase global ethanol demand by 50%. We then analyze the impact of these increases in terms of land-use change and commodity price changes particularly in Brazil. In the first scenario, we assume that the enforcement of the land-use reserve in Brazil remains at historically observed levels, and that abundant additional land can be readily incorporated into production. The second scenario involves implementing the same exogenous biofuel demand shock but with a different responsiveness in area expansion to price signals in Brazil, reflecting varying plausible assumptions on land availability for agricultural expansion. The third scenario, which is similar to the first scenario but with a larger increase in global ethanol demand, is run to check whether increasing volume of ethanol requires the incorporation of additional quantities of land per unit of ethanol. We find that, within Brazil, the expansion occurs mostly in the Southeast region. Additionally, total sugarcane area expansion in Brazil is higher than the increase in overall area used for agriculture. This implies that part of the sugarcane expansion displaced other crops and pasture that is not replaced, which suggests some intensification in land use. The lower land expansion elasticities in the second scenario result in a smaller expansion of area used for agricultural activities. A higher proportion of the expansion in sugarcane area occurs at the expense of pasture area, which implied land intensification of beef production. This explains the small change in commodity prices observed between the first and second scenarios. These results suggest that reducing the overall responsiveness of Brazilian agriculture may limit the land-use changes brought about by biofuel expansion, which would in turn reduce its environmental impacts in terms of land expansion. Additionally, the impacts on food prices are limited because of the ability of local producers to increase the intensity of land use in both crop (by double cropping and raising yields) and livestock production (by increasing the number of heads of cattle per hectare of pasture or stocking rate) releases area that can be used for crops. In scenario three, we find that larger ethanol volumes did not require more land per unit of ethanol. Doubling the demand for ethanol does not change the results, which indicates that the limit for intensification is beyond the 50% expansion assumed in Scenario 3. In this range, the same amount of land is incorporated into production per additional unit of ethanol.

Global Biofuel Expansion and the Demand for Brazilian Land: Intensification versus Expansion

Introduction

The rapid increase in global biofuel production and consumption, particularly of ethanol, has an associated derived demand for crops to produce the necessary feedstock. Per hectare yields translate feedstock needs into a corresponding demand for land. The rapid expansion in biofuel production can thus be linked to an increase in land demand for agricultural production purposes. It is in fact the land-use change impact, together with the diversion of food crops into energy that feeds most of the controversy surrounding biofuel expansion (Searchinger et al., 2008; Fargione et al., 2008; Fabiosa et al., 2010).

World production of fuel ethanol has increased from 39 billion liters to almost 73 billion liters from 2006 to 2009, according to F.O. Lichts (2010). The same source expects production of the fuel to reach 83 billion liters in 2010. A large proportion of the increase in ethanol consumption has been fueled by policies either mandating its use or providing financial incentives to make the fuel competitive with gasoline. The two largest producing countries, the US and Brazil, are expected to contribute a combined 88% of global production in 2010 (F.O. Lichts, 2010).

Brazil has been a pioneer in incorporating biofuels, particularly ethanol from sugarcane, into its fuel supply and is currently the largest exporter in the world ethanol market. As the demand for biofuels expands, Brazil is expected to continue to play a major role in meeting both domestic and global needs. Given the expected supply expansion, and the fact that Brazil is home to natural areas with a high degree of biodiversity, concern has been voiced regarding the potential of the global biofuel expansion to accelerate deforestation in the Amazon and Cerrados areas. Thus, how this increased production of biofuels will affect the agricultural and biofuel sectors in Brazil, as well as how it will affect land use, is a contentious topic given the potential environmental consequences.

The area devoted to agriculture in Brazil has expanded significantly in the recent past, including the area planted to sugarcane (see Table 1). Table 1 shows that sugarcane area grew at a much higher rate than that of other major crops. However, according to Nassar et al. (2008), most of the growth in the sugarcane crop occurred in previously utilized regions. In particular, the authors find that for the South-Central region (the area with the largest sugarcane expansion), 98% of the sugarcane area growth in 2007 and 2008 was on land previously used for agriculture (53%) or pasture (45%). While this hints that sugarcane ethanol is not directly responsible for the clearing of new areas for agricultural activities, it also does not rule out an increase in the use of previously unused (natural or idled) land in order to partially replace the product from the uses displaced by sugarcane. The need for additional area is only eliminated when the demand for the products from other land-using activities declines, or when crop yields per hectare increase by a sufficient amount to compensate for the area lost to sugarcane.

Table 1. Area Change for Major Land-Using Agricultural Activities in Brazil (1000 hectares)

	1999/2000	2008/2009	Change	% Change
Sugarcane	4,880	8,423	3,544	73%
Major Crops[a] (excluding sugarcane)	36,594	46,290	9,697	26%
Major Crops (including sugarcane)	41,473	54,714	13,240	32%
Pasture	195,025	203,873	8,848	5%
Total	236,498	258,587	22,089	9%

Source: Prepared based on the Brazilian Institute of Geography and Statistics (IBGE) and the Brazilian Ministry of Agriculture's National Supply Company (CONAB) data. [a] Major crops include corn (1st and 2nd crops), soybeans, rice, cotton, dry beans (1st and 2nd crops), wheat, barley, and sugarcane.

In terms of regional distribution of sugarcane, the South-Central region (comprising the states of Sao Paulo, Minas Gerais, Paraná, Mato Grosso, Mato Grosso do Sul, and Goias) accounted for about 82% of the total area in 2008, and for 96% of the expansion between 2005 and 2008 (Nassar et al., 2008). While the Northeast region's area seems to be relatively stable over time, these authors indicate that states in the northeast Cerrados region (e.g., Maranhao, Tocantins, and Piaui) are a promising area for the expansion of sugarcane.

In this study, we analyze the regional land-use changes in Brazil that would result from an increase in the consumption of ethanol beyond the levels projected in a business-as-usual scenario. Special attention is paid to the regional expansion of sugarcane area, and the additional area that needs to be incorporated into agricultural uses to accommodate that expansion. The impact of the expansion on the prices of major commodities is also estimated. This analysis is conducted under three different scenarios. In the first scenario, we assume that the enforcement of the land-use reserve remains at the levels observed in the recent past, and that abundant additional land can be readily incorporated into production.[1] In the second scenario, we assume a less abundant supply of land for agricultural expansion. This could be the result, for example, of enhanced enforcement of the land reserve requirements. In this second scenario, the supply of agricultural commodities in Brazil becomes more inelastic (compared to the previous scenario), resulting in area expansion in other regions of the world, coupled with higher prices. A different pattern of substitution can also be expected within the country, as different activities can react differently to the limitations to land expansion. A model of world agriculture—able to project land use, production, consumption, and trade, as well as commodity prices—is used for the analysis. The third scenario, which is similar to the first scenario but with a larger increase in global ethanol demand, is run to check whether increasing volume of ethanol requires the incorporation of additional quantities of land per unit of ethanol.

[1] In current Brazilian law, producers must keep in reserve a portion of their land (i.e., in its natural form). This proportion varies regionally from 20% in the established regions (e.g., South) to 80% in the Amazon area.

The chapter is organized as follows. A description of the models used in the study is provided next with additional details on the regional Brazil and world ethanol components. Section 3 describes the scenarios to be analyzed. Results from the models are presented and discussed in section 4. Finally, section 5 offers some concluding remarks.

Model Description

Overview of the Modeling System

The international FAPRI model is a system of econometric, multi-market, non-spatial, partial equilibrium models.[2] It covers all major temperate crops, ethanol, sugar, biodiesel, dairy, and livestock products in all the major producing and consuming countries (see Figure 1). The model is run in yearly time steps.

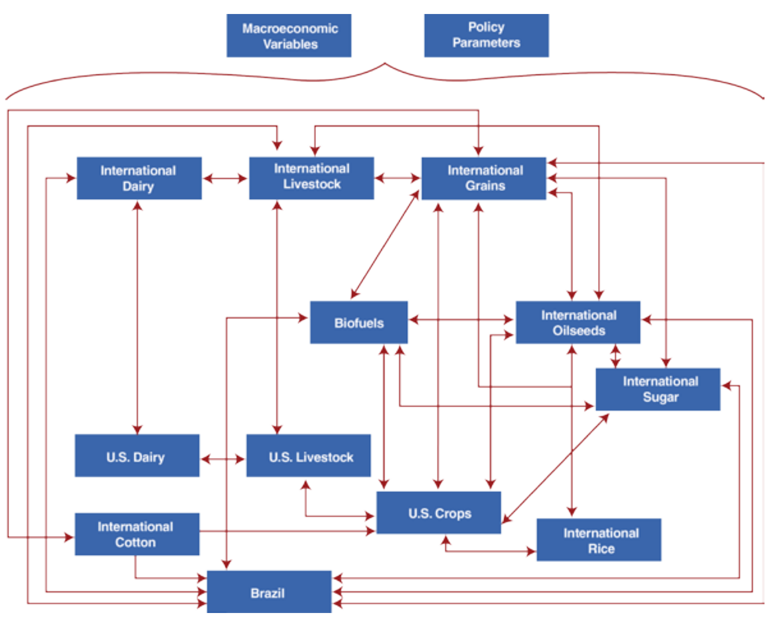


Figure 1. FAPRI-CARD Model Interactions

Note: The model interactions represent trade, prices, and physical flows. All models in the system were run, with the exception of international rice.

[2] FAPRI is the Food and Agricultural Policy Research Institute at Iowa State University. A more detailed description of the FAPRI modeling system, including data and elasticities, is provided at http://www.fapri.iastate.edu/models/.

To name a few applications, this modeling system has been used extensively to create market outlooks, to analyze the impacts of technical change, and to provide policy analysis. Results from these analyses have led to peer reviewed and other academic publications (see, e.g., FAPRI, 2010; Fabiosa et al., 2007; Fabiosa et al., 2010; Hayes et al., 2009; Tokgoz et al., 2008). Additional validation through external reviews and internal updates are periodically performed.

Interactions among markets are reflected through extensive linkages that capture derived demands for feed in livestock sectors, feedstock in biofuel production, substitution possibilities between close substitutes, and competition for land. The modeling of these biological, technical and economic relations is based on accepted relationships in agricultural production and markets, and on analysis of historical data.

The model finds a set of prices for each commodity such that supply equals demand for all commodities and countries. Through the linkages, changes in one commodity or country affect the markets for other commodities or countries. In general terms, agricultural production results from the area allocated to the different crops multiplied by the crop's yield. The area allocated to the different crops depends on crops' relative expected returns. This captures the competition for land between these activities. Beginning stocks complete the domestic supply quantities available. The domestic demand specification depends on the commodity and can include food uses, feed uses, industrial uses, and ending stocks.

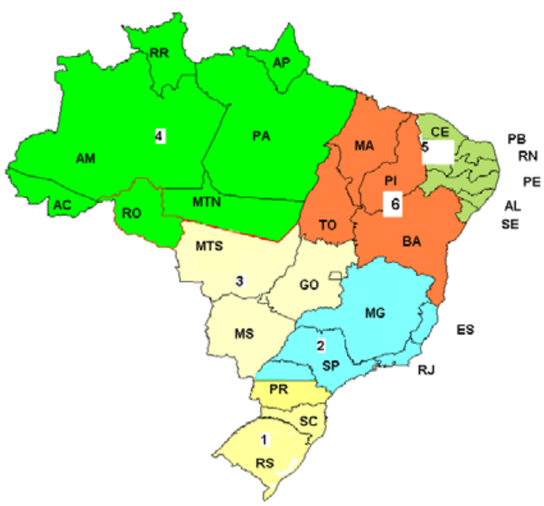
The Regional Brazil Model

Brazil encompasses widely varying ecosystems, ranging from grassland and crops in the South to tropical forests in the North and semiarid areas in the Northeast. The different regions present large disparities in terms of infrastructure and natural resources available to increase agricultural production. Thus, while rapid expansion of production of some commodities may be achieved only by displacing other agricultural activities in land-constrained regions, increases in area used by all activities may be observed in other parts of the country. This points to distinct dynamics in the competition for land across space. Environmental (both local and global through the emission of greenhouse gases), social, and economic impacts hinge critically on the nature of these land-use changes. Therefore, it is becoming increasingly important to recognize the spatial dimension of the agricultural expansion. Given the emerging importance of Brazil, both in terms of its capabilities to expand area (and production) in response to demand changes and its potential for greenhouse gas emissions from land clearing, a regional model of Brazilian agriculture was developed.[3] This model is fully integrated as a part of the FAPRI modeling system.

The model of Brazilian agricultural production incorporates major crops, biofuels, and livestock interacting and competing for agricultural resources, in particular, land. Outputs from the model include projections of supply and utilization variables, and the amount of land allocated to the activities considered. On the crops side, we consider corn (1st and 2nd crop), the soybeans complex (including soybean meal, soybean oil, and biodiesel), the sugarcane complex (including sugar and ethanol), rice, cotton, and dry beans (multiple cropping depending on the region). The modeled animal products are beef, pork, poultry, and dairy. In terms of land allocation, the area used by a given activity depends on its expected real returns in comparison to expected returns of activities that compete for the resource. Land used for pasture is explicitly modeled. Since not all the regions considered are equally suited for different activities, the competition for land is contingent on the location. As such, not all activities compete with each other with the same intensity in all regions. Additionally, the model also allows for production costs, yields, and prices to vary by region.

[3] The Brazilian model was developed by the Center for Agricultural and Rural Development at Iowa State University in collaboration with the Institute for International Trade Negotiations (ICONE), Brazil.

Through the use of spatially disaggregated information on historical production activities and land availability, the model is able to determine the relative profitability of different activities at the local level, which will drive regional supply curves for relevant commodities and their associated land use. For this modeling effort Brazil is divided into six regions: South, Southeast, Central-West Cerrados, Amazon Biome, Northeast, and North-Northeast Cerrados. Figure 2 presents the regional disaggregation of Brazil, including the states that make up each region. The model is able to capture the regional differences in terms of capabilities and consequences of the expansion. In this way, the impacts of land-use changes derived from increasing demand for agricultural products can be more precisely established.



Region 1: South
Rio Grande Do Sul; Santa Catarina; Parana
Region 2: Southeast
Sao Paulo; Rio De Janeiro; Espirito Santo; Minas Gerais; Parana
Region 3: Central-West Cerrados
Mato Grosso Do Sul; Goias; Distrito Federal; Mato Grosso
Region 4: Amazon Biome
Rondonia; Amazonas; Para; Roraima; Amapa; Acre; Mato Grosso
Region 5: Northeast
Ceara; Paraiba; Rio Grande Do Norte; Pernambuco; Alagoas; Sergipe
Region 6: North-Northeast Cerrados
Tocantins; Bahia; Maranhao; Piaui

Figure 2. Regional Disaggregation of the CARD Brazil Model

Given that the focus of this chapter is on Brazil's agriculture, more detail on the Brazilian regional model, and in particular the land allocation mechanism, is warranted. Two different procedures are used to project agricultural area and allocate it to land-using activities. For crops deemed not to directly compete for land resources during the main growing season, behavioral equations that project agricultural area are used. These equations are mainly driven by real relative returns of the different activities. Wheat, barley, the second crop of corn, and the second crop of dry beans fall into this category. The area allocated to a second group of activities, competing for land resources in time and space, is modeled using a two-step approach. The total area utilized for agricultural activities is determined first. A second step allocates this area to the competing land uses. Corn, soybeans, rice, cotton, dry beans, sugarcane, and pasture are modeled through this procedure.

The first step, the calculation of the total area to be used for agriculture in each region, is dependent on expected returns to agriculture and potential land availability as follows:

$$A_{jt}^{ag} = A_j^T m_j\left(\overline{r}_{jt}\right),$$

where $\overline{r}_{jt}$ denotes expected returns to land uses (crops and pasture) in region *j* and year *t*, and $m_j\left(\overline{r}_{jt}\right)$ is the share of the potential agricultural land $\left(A_j^T\right)$ that is used in that region and year. Expected returns to agriculture are projected as (area) weighted average expected returns for the different activities covered, using the following equation:

$$\overline{r}_{jt} = \overline{r}_{jt-1} * \sum_{i=1}^{I}\left(\frac{\tilde{A}_{ijt}}{A_{jt}^{ag}}\left(1+\frac{r_{ijt}-r_{ijt-1}}{r_{ijt-1}}\right)\right),$$

where $\tilde{A}_{ijt}$ and r_{ijt} denote the area allocated and expected returns to activity $i=1,2,\ldots,I$, in region *j* and year *t*, respectively. A linear allocation method proposed by Holt (1999) is used to share the area out to the different activities. The share of the total area allocated to a given activity $\left(v_{ijt}\right)$ is determined as

$$v_{ijt} = b_{ij} + \sum_{i=1}^{I} s_{ij} * r_{ijt} ,$$

where s_{ij} are coefficients, and $\sum_{i=1}^{I} v_{ijt} = 1$ for all *j* and *t*. Therefore, the area allocated to a crop is given by

$$\tilde{A}_{ijt} = A^{ag}_{jt} * v_{ijt} .$$

In this framework, the own-price elasticity for the area allocated to a crop can be decomposed into a "scale effect" and a "competition effect" as $\varepsilon_{ij} = \varepsilon^{scale}_{ij} + \varepsilon^{comp}_{ij}$. The first term captures the additional area for a crop given an expansion in total area in response to that crop's returns. The second term governs the area the crop competes away from other activities as its expected returns increase. It is easy to show that the scale effect is $\varepsilon^{scale}_{ij} = \varepsilon^{Ag,j}_{r_j} * \varepsilon^{r_j}_{r_{ij}}$, where $\varepsilon^{Ag,j}_{r_j}$ is the elasticity of agricultural area to average expected returns to agriculture, and $\varepsilon^{r_j}_{r_{ij}}$ denotes the elasticity of expected agricultural returns to the returns of activity *i*. The subscript *j* denotes the region. Table 2 presents the elasticities used in the model. Clearly, the Central-West Cerrados and the Amazon area are the regions (given the land availability) that will present the highest response to changes in agricultural returns. Long-established regions and regions with land limitations have lower area elasticities. Also, soybeans and sugarcane are the most returns-responsive crops in the model.

Table 2. Regional Land-Use Elasticities and Own-Price Elasticities for Activities in the Brazil Model

Region	$\varepsilon^{Ag,j}_{r_j}$	Corn 1st crop	Soybeans	Cotton	Rice	Dry beans 1st crop	Sugarcane	Pasture
South	0.06	0.18	0.43	0.21	0.15	0.09	0.40	0.03
South East	0.07	0.20	0.43	0.21	0.12	0.10	0.40	0.05
Central West	0.18	0.20	0.48	0.25	0.13	0.10	0.43	0.11
North	0.25	0.20	0.45	0.25	0.15	0.09	0.20	0.24
Northeast Coast	0.01	0.22	0.00*	0.20	0.13	0.10	0.39	0.01
Northeast Cerrados	0.10	0.19	0.44	0.22	0.13	0.10	0.40	0.07
Brazil	0.13							

[a] Soybeans are not planted in this region.

The supply side of the livestock sector is also regionalized in the model. The products modeled are pork, beef, poultry, and dairy. While poultry production is modeled directly through a behavioral equation depending on regional prices and costs of production, the stocks of animals are tracked over time, and production levels are consistent with the evolution of these stocks. Given stocks of cows and sows, the number of calves and piglets are obtained (through projected birth rates). Adult animals not part of the breeding herd are allocated to an "other" category. Meat production numbers are obtained by multiplying the projected number of animals slaughtered in each category by a slaughter weight. The numbers of slaughtered and dead animals are used to calculate the beginning stocks for the following year.

It is worth noting that the model allows for feedback between the pasture area and the size of the cattle herd. This is an important feature, as beef production is by far the largest user of pasture. The link is captured by modeling the stocking rate directly, which depends on the profitability of beef production. This profitability will in turn affect the amount of area devoted to pasture, through the land allocation mechanism described earlier.

The Ethanol Model

While its structure is country specific, in its basic form, the international ethanol model is based on behavioral equations for production, consumption, stocks, and trade. Of the eight countries covered, complete models are set up for the United States, Brazil, China, European Union, and India. Net trade equations are established for Japan, South Korea, and an aggregate called rest-of-the-world. A representative ethanol price for the world (Brazilian anhydrous ethanol price) is solved endogenously to equate excess supply and excess demand for all the countries. For most countries, the domestic price is determined through a price transmission from the world price, adjusted by exchange rate and relevant policies. An exception is the US, which is nearly insulated from the world market, given its import tariffs on non-preferential ethanol imports.[4] The US model solves endogenously for the ethanol price that clears the domestic market (unless international prices are low enough relative to the domestic price).[5]

The derived demand for ethanol feedstock is country specific. While sugarcane is the main feedstock in Brazil, corn and wheat are responsible for most of the ethanol production in the US and the EU, respectively. Brazil is the only consistent net exporter of ethanol in the model. The area allocated to sugarcane in the country depends on the expected returns to this crop, relative to other potential activities competing for land. Expected returns to sugarcane follow from a composite of the expected prices of sugar and ethanol, and sugar content of the cane. The fraction of the total recoverable sugar (the feedstock for sugar and ethanol) used to produce ethanol depends on the price of ethanol relative to that of sugar. The remainder is used for sugar production.

On the domestic demand side (for transport), ethanol is consumed in anhydrous and hydrous forms. The anhydrous form is consumed in mandatory blends with gasoline (25% ethanol), by gasoline cars. Hydrous ethanol is mainly used by flexible fuel vehicles (FFVs) but also by gasohol cars. FFV owners can choose between ethanol and gasoline (blended), and their choice is quite sensitive to the relative prices of these two fuels.

---

[4] For more details on the US ethanol model, see FAPRI, 2008.

[5] The US ethanol model is embedded in the US crops model (see Figure 1) and has a more detailed model structure than what is described here. The US crops model was developed and is maintained by FAPRI at the University of Missouri, Columbia. For more details, see FAPRI, 2004.

Scenarios

Baseline

In order to isolate the impacts of a specific change being analyzed, a reference trajectory or baseline needs to be established for all the variables of interest. This baseline reflects continuity of current policies, in a business-as-usual environment. As such, the baseline already incorporates a significant global expansion of the ethanol sector, and growth of agricultural areas in most regions of Brazil, including an expansion of sugarcane area. Scenario analysis allows us to study how changes in a single or a subset of factors affect the market outcome and the impacts on the variables of interest. The new equilibrium is then compared to the benchmark or baseline trajectory.

Scenario 1—A 25% increase in global ethanol consumption

For this scenario, we shock the demand for ethanol in each country with a 25% exogenous (and permanent) expansion. After introducing the shock, all the markets are allowed to react to the expanded ethanol demand. The initial impact of the shock will be an increase in the price of ethanol, which will discipline the demand expansion and lead to enhanced ethanol supplies. The impact of the derived additional demand for ethanol feedstocks, as well as the increased supply of ethanol by-products, will be then transmitted to the markets for other commodities and countries. As a result, we expect additional land being used for agricultural production, as well as higher crop prices as the competition for area intensifies. Because Brazil is the largest world ethanol exporter, and has a demonstrated potential to expand agricultural production, a large proportion of the adjustment is expected to occur in that country. This ability to expand agricultural production is expected to moderate the price increase brought about by the expanded ethanol demand.

Scenario 2—A 25% increase in global ethanol consumption with limited land expansion in Brazil

For the second scenario, we combine the exogenous expansion in global ethanol demand with a limit of land-use expansion in Brazil. For example, the Brazilian government may decide to impose tighter enforcement of regulations, limiting the area expansion in the country. This additional factor has the impact of limiting the country's ability to respond by increasing agricultural area. The motivation for this scenario is the growing pressure being exerted by the international community, environmental organizations, and the Brazilian government to curb land-use conversion, and deforestation in particular. This scenario is implemented by halving the area expansion elasticities of the different regions. Thus, the same increase in returns to agricultural production will result in a lower expansion in output. In other words, the same supply expansion will need higher price changes to materialize.

While restrictions in area expansion through, for example, tighter regulations are expected to reduce land-use change, and therefore deforestation in Brazil, a partially compensating change can be expected in other regions (leakage), coupled with larger commodity price changes. In this case, curbing the increase in emission of greenhouse gases comes at a cost of higher food prices.

Scenario 3—A 50% increase in global ethanol consumption

For this scenario, we revert back to the original land expansion elasiticities and increase the size of the global consumption shock to 50%. The objective of this scenario is to explore whether additional land per unit of ethanol would be required as the levels of ethanol produced are increased.

Results

Scenario 1 Results

The increase in global ethanol use affects not only production but also trade of the biofuel. The changes, which are country specific, are presented in Table 3 for year 2022, the last year of modeling. As mentioned before, the increase in ethanol prices in response to the additional demand disciplines the global utilization increase to be below the size of the shock (25%). At the new equilibrium, global consumption increased by 18.3%, or 28,469 million liters, relative to the baseline. With the exception of Brazil, all countries listed in Table 3 are net importers of ethanol.

Table 3. Change in Ethanol Production, Consumption, and Trade in 2022 for Scenario 1

Countries	Production		Consumption		Net Exports[a]	
	Million Liters	%	Million Liters	%	Million Liters	%
Brazil	13948	21.21%	8281	20.83%	5670	21.75%
Canada	2	0.13%	1189	24.68%	-1187	33.66%
China	100	3.81%	712	22.73%	-611	123.23%
EU	156	2.17%	2306	23.42%	-2151	80.84%
India	179	7.22%	650	20.95%	-470	71.22%
US	14103	18.53%	14215	15.85%	-135	-0.98%
Japan	-	-	489	22.35%	-489	22.35%
South Korea	-	-	325	22.89%	-325	22.89%
Rest of the world	-	-	302	23.95%	-302	23.95%
World[b]	28488	18.33%	28469	18.34%	5670	21.75%

[a] A positive number denotes an increase in net exports (reduction in net imports). A negative number represents an increase in net imports (reduction in net exports). [b] World production and consumption changes differ by changes in ending stocks.

While the consumption in all countries increased by a percentage similar to that in the shock, production and trade changes varied by country. For the case of the US, the increase in consumption is mostly supplied by a commensurate expansion in domestic production, with a relatively minor change in trade. It is also worth noting that the demand for high blends such as E-85 is fairly elastic, as FFV drivers can revert to gasoline whenever the price of ethanol increases relative to that of the fossil fuel. It is this fact that reduces consumption more in the US relative to that in other countries presented in Table 3 (when compared to the initial increase in ethanol demand). Given the large market penetration of FFVs in Brazil, the demand for ethanol is also relatively elastic in that country. The table also shows that a high proportion of the additional demand in countries other than the US is supplied by increased exports from Brazil. An important implication is that the expansion of ethanol production based on grains is limited to the additional fuel consumed in the US and to a lesser extent to expanded production in China and the EU. This muted grain-based ethanol production expansion will dampen the effects in the market for grain feedstocks, mostly corn and wheat. Table 4 shows the percent change of the price of selected commodities, and the global change in area harvested of these commodities.

The prices of all the commodities presented here increase in response to the increase in global ethanol production and consumption. The shock is introduced in the model as an exogenous increase in demand; thus, the new equilibrium price of ethanol for the scenario is higher than in the baseline. The prices of feedstocks for ethanol production such as corn also increase, reflecting the enhanced derived demand for these products. The increase in the prices of most of the other commodities is due to their reduced supply, as additional land is claimed by ethanol feedstocks.

Table 4. Change in the Prices and Areas of Selected Commodities in 2022 for Scenario 1

	Price change	Area change	
	%	(1000 hectares)	%
Ethanol	35.79%	-	-
Sugar	4.27%	-	-
Sugarcane	-	1384	4.74%
Corn	2.71%	1606	1.00%
Soybeans	0.61%	-362	-0.32%
Wheat	1.06%	-99	-0.04%
Sorghum	1.43%	55	0.13%
Barley	1.37%	-5	-0.01%
Other crops[a]	-	-94	-0.11%
Total	-	2485	0.35%

[a] Other crops include rapeseed, sunflower, peanuts, and sugar beets.

As previously mentioned, Table 3 shows that most of the increased consumption in countries other than the US is met by an expansion of Brazilian production and exports. The feedstock needed for the additional ethanol production in Brazil is obtained from two sources, an increase in the area devoted to sugarcane, and an increase in the proportion of the recoverable sugars in the sugarcane used for ethanol, at the expense of sugar. This latter source reflects a decline in the production of sugar and an increase in the price of the sweetener (see Table 4). The regional distribution of the increase in sugarcane area is presented in Table 5.

Table 5. Regional Changes in the Area Used for Agriculture in Brazil in 2022 for Scenario 1

Region	Sugarcane	Other 1st Crops[a]	2nd Crops[b]	Area Planted	Pasture	Area Used
	(1)	(2)	(3)	(4)=(1)+(2)+(3)	(5)	(6)=(4)+(5)-(3)
			(1000 hectares)			
South	74.7	-16.3	106.7	165.1	5.8	64.2
Southeast	991.2	-236.5	13.6	768.3	-377.3	377.5
Central West	115.9	104.8	102.7	323.4	-94.7	126.0
North	10.0	57.9	3.1	71.0	66.7	134.5
Northeast Coast	143.2	36.8	0.0	180.0	-127.1	52.9
Northeast Cerrados	17.3	53.1	12.5	82.9	-23.8	46.6
Brazil	1352.3	-0.1	238.6	1590.8	-550.5	801.7

[a] Includes corn, soybeans, cotton, rice, and dry beans. [b] Includes the 2nd crops of corn and dry beans, wheat, and barley. As winter crops, the latter two crops are assumed to be mostly double cropped with summer crops.

The estimated country-level increase in sugarcane area as a result of the surge in ethanol demand is about 1.4 million hectares, an 11.2% increase from baseline levels. As expected, most of the expansion is projected to occur in the Southeast, the region with the largest sugarcane area and the highest growth rate in the recent past. This region is followed by the Northeast Coast, and the Central West, a region in which the ethanol industry is currently expanding.

While the increase in ethanol consumption leads to the expansion of sugarcane area, as well as that of other crops (especially the second corn crop), total agricultural area expansion is lower than the combined increase in all crops. The area planted to crops increases by 1.6 million hectares. However, at 802,000 hectares, the expansion in the land used for agriculture is lower. This implies that the model is projecting some of the crop expansion to occur in areas already in use for agriculture. In particular, some of the crop area expands over pasture, partially offsetting the demand for additional land and the pressure on natural landscapes. The increase of cropped area into pasture is accommodated by an increase in the intensity with which pastures are used, as evidenced by higher stocking rates (stock of cattle divided by pasture area) shown in Table 6. The largest levels of pasture use intensification can be observed in the regions with difficulties in incorporating additional land and facing the most pressure for sugarcane expansion (e.g., Southeast and Northeast Coastal). While additional sugarcane area is expected in the Central West, the availability of land for expansion dampens the need for intensification in pasture usage. The rest of the difference between the increase in total agricultural area and the increase in total crop area is accounted for by an increase in the area that is double cropped (see Table 5). Thus, intensification in land use reduces the need for the expansion of agriculture into previously unused areas.

Table 6. Change in the Stocking Rate of Pastures (Stock of Cattle Divided by Pasture Area) by Region in 2022 for Scenario 1

Region	Change in stocking rate
South	0.069%
Southeast	0.702%
Central West	0.269%
North	0.234%
Northeast Coast	0.942%
Northeast Cerrados	0.196%
Brazil	0.356%

An important portion of the expansion in crop area (other than sugarcane) can be attributed to the need to partially replace grains used to produce ethanol. As an example, an increase in corn-based ethanol production in the US will result in a reduction in exports of about

7.5 million tons (11%). Ceteris paribus, the generated excess demand for the rest of the world will push corn prices up and increase crop area in Brazil.

Scenario 2 Results

We turn our attention next to the implications of restricting the ability of producers in Brazil to increase their area under production. Given the additional constraints to land expansion in Brazil, we would expect that larger price increases would be needed to bring about a sufficient supply of agricultural products and to increase agricultural area in Brazil and in other countries to compensate for the diminished supply expansion in Brazil. The results indicated however, that the restriction in land expansion had a limited impact on prices and crop areas, given the size of the demand shock and the scope for intensification in production of the livestock sector and of double cropping.

The equilibrium changes in production, consumption, and trade of ethanol as a result of the introduced shock to the system are virtually unchanged from those observed in the first scenario, and thus are not repeated here. This is because additional ethanol supplies were obtained with a marginal price change in the model, limiting the price transmission to other commodities. Again, most of the additional demand is met through expanded exports by Brazil. Most of the consumption expansion in the US is supplied through domestic sources.

Given the constrained ability of Brazilian producers to respond to price changes as land-use restrictions are more tightly enforced in this scenario, prices for ethanol and its feedstocks were expected to increase more than in scenario 1 (see Table 7). However, as mentioned, the price changes are only marginally different from those observed in the first scenario. Additionally, total area devoted to agriculture does not expand as much as before. The reduced ability to expand area in Brazil did not significantly constrain the country's ability to increase ethanol supply because of the same intensification in land use observed in scenario 1.

Table 7. Change in the prices and areas of selected commodities in 2022 for Scenario 2

	Price change	**Area change**	
	%	1000 hectares	%
Ethanol	35.85%	-	-
Sugar	4.34%	-	-
Sugarcane	-	1380	4.72%
Corn	2.72%	1604	0.99%
Soybeans	0.61%	-363	-0.32%
Wheat	1.07%	-99	-0.04%
Sorghum	1.44%	55	0.13%
Barley	1.37%	-5	-0.01%
Other crops[a]	-	-95	-0.11%
Total	-	2478	0.35%

[a] Other crops include rapeseed, sunflower, peanuts, and sugar beets.

Driven by the assumption of a lower area expansion elasticity, the area used for agriculture in Brazil increases by a smaller amount when compared to the first scenario (see Table 8). While the total area planted with crops (column 4 in Tables 5 and 8) increases by a similar amount relative to that of scenario 1, the area used for agricultural activities (column 6) is about 15% lower in the second scenario. In terms of total expansion, we find that the crop area growth (including sugarcane) occurs to a higher extent in pasture area, increasing the intensification of land use and reducing the need to incorporate additional area into production. Thus, deforestation is reduced relative to scenario 1, limiting the impacts in terms of emissions of greenhouse gases.

The relatively small impact of limiting producers' ability to expand into new areas, through a policy such as tightening the enforcement of land reserve restrictions, is crucially dependent on the size of the demand shock introduced and the room for intensification embedded in the established baseline. As the scope for land-use intensification is exhausted, additional biofuel quantities can be expected to be produced only by incorporating new land into production. In this situation, limitations on land expansion would have larger consequences for commodity prices.

Table 8. Regional Changes in the Area Used for Agriculture in Brazil in 2022 for Scenario 2

Region	Sugarcane	Other 1st Crops[a]	2nd Crops[b]	Area Planted	Pasture	Area Used
	(1)	(2)	(3)	(4)=(1)+(2)+(3)	(5)	(6)=(4)+(5)-(3)
				(1000 hectares)		
South	74.6	-25.9	107.4	156.1	-5.4	43.3
Southeast	986.8	-242.1	13.7	758.4	-429.8	314.9
Central West	117.7	114.7	103.2	335.6	-56.6	175.9
North	9.8	54.2	3.1	67.1	15.3	79.3
Northeast Coast	141.3	33.2	0.0	174.5	-143.1	31.4
Northeast Cerrados	17.3	52.3	12.6	82.2	-34.7	34.9
Brazil	1347.5	-13.6	240.1	1574.0	-654.2	679.7

[a] Includes corn, soybeans, cotton, rice, and dry beans. [b] Includes the 2nd crops of corn and dry beans, wheat, and barley. As winter crops, the latter two crops are assumed to be mostly double cropped with summer crops.

Scenario 3 Results

The goal of running this scenario was to analyze the impact of increases in the amount of ethanol that needs to be produced on the additional demand for area. In particular, we wanted to explore how the additional demand for ethanol production translated into increasing areas, and whether we can expect that the areas needed per unit of additional ethanol production increase or remains constant, when normalized by magnitude of the additional demand. Also, the scenarios allow us to calculate the additional amount of land that is expected to be incorporated into production per million liters of ethanol expansion, and the sensitivity to the size of the shock and the potential restrictions for expansion brought about for example through tighter enforcement of regulations. Results are presented in table 9.

Table 9. Additional land required

	Additional land (1000 hectares)	Additional production (million liters)	Normalized (hectares/million liters)
Scenario 1	801.7	14910	53.8
Scenario 2	679.7	14901	45.6
Scenario 3	1575.5	29644	53.1

As a benchmark, and considering yields in the main sugarcane production region in Brazil (the Southeast, which is where most of the expansion occurs in the scenarios), about 100 hectares of the crop are needed to produce 1 million liters of ethanol.[6] Table 9 shows that in equilibrium and after all markets adjust and production intensifies, we only need about half of the numbers of hectares for all scenarios. These results do not dependent on the magnitude of the shock (when comparing scenarios 1 and 3). However, what is important is restricting the ability of producers to incorporate additional land into new areas (scenario 2). Our results indicate that halving the land expansion elasticities reduces the need for additional area per million liters by 15%, from 53.8 to 45.6 hectares per million liters of ethanol.

Concluding Remarks

Global biofuel production and consumption has an associated derived demand for crops to produce the necessary feedstock, and corresponding land-use requirements. A spatially disaggregated model of Brazilian agriculture, part of the FAPRI modeling system of world agriculture, is used to assess the implications of global biofuel expansion on Brazilian land use at the regional level.

We find that most of the expansion in global ethanol consumption outside the US is met by Brazilian ethanol production, which leads to an increase in the area devoted to sugarcane.

[6] We assume sugarcane yields for 2023 in the Southeast region of 113.5 tons of sugarcane per hectare, 0.155 tons of recoverable sugars per ton of sugarcane, and 581.3 liters of ethanol per ton of recoverable sugars.

However, a large proportion of the sugarcane area expansion occurs in area already in agricultural use. For example, for the Southeast region, about 62% of the expansion of sugarcane area is accommodated by a decline in area of pasture and other crops. This proportion increases to 68% when land expansion limitations are introduced (scenario 2). In the Northeast region, virtually all the sugarcane area expansion comes at the expense of pasture. The trade-offs between crops and pastures are not as apparent in regions with larger reserves of available land such as the Central West and the North.

The results suggest that reducing the overall responsiveness of Brazilian agriculture may limit the land-use changes brought about by biofuel expansion, which would in turn reduce its environmental impacts in terms of land expansion. The impacts on food prices are limited here because of the ability of local producers to increase the intensity of land use in both crop and livestock production. For crops, the intensification of land use is achieved in this case by increasing the prevalence of double cropping, and by raising crop yields. Increasing the number of heads of cattle per hectare of pasture (stocking rate) releases area that can be used for crops. Both of these land-use intensification mechanisms, however, have their limits. Once exhausted, larger quantities of land will need to be incorporated into production, and higher commodity prices will result per unit of additional biofuel demand. Doubling the demand for ethanol does not change the results, which indicates that the limit for intensification is beyond the 50% expansion assumed in Scenario 3. In this range, the same amount of land is incorporated into production per additional unit of ethanol.

References

Fabiosa, J.F., Beghin, J., Dong, F., Elobeid, A., Fuller, F., Matthey, H., Tokgoz, S., Wailes, E., 2007. The impact of the European enlargement and CAP reforms on agricultural markets: Much ado about nothing? *Journal of International Agricultural Trade and Development*. 3(1), 57-69.

Fabiosa, J.F.; Beghin, J.C., Dong, F., Elobeid, A., Tokgoz, S., Yu, T., 2010. Land allocation effects of the global ethanol surge: Predictions from the international FAPRI model. *Land Economics*. Forthcoming.

FAPRI, 2004. Documentation of the FAPRI modeling system. FAPRI-UMC Report # 12-04, Food and Agricultural Policy Research Institute, University of Missouri, Columbia.

FAPRI, 2008. Model of the US ethanol market. FAPRI-UMC Report # 07-08, Food and Agricultural Policy Research Institute, University of Missouri, Columbia.

FAPRI, 2010. FAPRI 2010 U.S. and World Agricultural Outlook. Food and Agricultural Policy Research Institute, Iowa State University and University of Missouri, Staff Report 1-09, ISSN 1534-4533, Ames, Iowa.

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. *Science*. 319(5867), 1235-1238 [DOI: 10.1126/science.1152747].

F.O. Lichts, 2010. World ethanol production to approach 100 billion litre mark in 2010. World Ethanol & Biofuels Report. April 28.

Hayes, D.J., Babcock, B.A., Fabiosa, J., Tokgoz, S., Elobeid, A., Yu, T., Dong, F., Hart, C., Thompson, W., Meyer, S., Chavez, E., Pan, S., 2009. Biofuels: Potential production capacity, effects on grain and livestock sectors, and implications for food prices and consumers. *Journal of Agriculture and Applied Economics*. 41, 2(August), 465-491.

Nassar, A.M., Rudorff, B.F.T., Barcellos-Antoniazzi, L., Alves de Aguirar, D., Rumenos-Piedade-Bianchi, M., Adami, M., 2008. Prospects of the sugarcane expansion in Brazil: Impacts on direct and indirect land use change. Chap. 3 in: Zuurbier, P., van de Vooren, J., (Eds.), Contributions to Climate Change Mitigation and the Environment, Wageningen Academic Publishers, The Netherlands.

Searchinger, T., Heimlich, R., Houghton, R., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Yu, T., 2008. Factoring greenhouse gas emissions from land use change into biofuel calculations. *Science*. 319(5867), 1238-1240 [DOI: 10.1126/science.1151861].

Tokgoz, S., Elobeid, A., Fabiosa, J., Hayes, D.J., Babcock, B.A., Yu, T., Dong, F., and Hart, C.E., 2008. Bottlenecks, drought and oil price spikes: Impact on U.S. ethanol and agricultural sectors. *Review of Agricultural Economics*. 30(4), 604-622.