Comparing the trends and strength of determinants to deforestation in the Brazilian Amazon in consideration of biofuel policies in Brazil and the United States

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Introduction

Recent assessments of the lifecycle greenhouse gas (GHG) emissions associated with increased production of liquid biofuels in the U.S. have found that a relatively large share of these emissions is related to land-use change in other countries. For example, the California Air Resources Board (CARB) estimates GHG emissions from international land-use change to account for 29% to 69% of total emissions while EPA calculates GHG emissions from this source to account for 35% of total emissions (CARB, 2009; EPA, 2010). However, most of the existing analyses including EPA's RFS assumptions about indirect land-use change (ILUC) do not reflect recent data on deforestation rates in Brazil, which have been declining in the last 5 years. There is emerging evidence that the dynamics behind land-use change in Brazil may have changed since EPA's analysis. For example, the Brazilian government has in recent years made a public commitment to reduce deforestation through stronger enforcement of deforestation and land-use laws already on the books. There seems to be evidence that agricultural producers in Brazil are intensifying crop and livestock production and incorporating new land at lower rates than in the recent past. Additionally, the competition for forestry areas, and in particular between agriculture, pastures, and planted forests is poorly understood, and not explicitly taken into account in previous assessments in several modeling exercises. If the dynamics of deforestation in Brazil have changed since EPA's analysis, then the relationships, parameters and results obtained by EPA and others should to be reevaluated.

The objective of this paper is to outline the economic and political drivers of deforestation in the Brazilian Amazon, to depict trends in those drivers and trends in deforestation over the past 10 years, and to assess the responsiveness of certain drivers to changes in agricultural, biofuel, and land use policies both in the United States and Brazil. Specifically, a model of the Brazilian forest sector is developed and incorporated into the CARD/FAPRI modeling system in order to allow for policy simulations used to illustrate land-use changes in the U.S. and Brazil in response to different assumptions regarding land-use and biofuel policies.[1] The purpose of the study is to better understand how policies designed to increase production of liquid biofuels, both in Brazil and in the United States, may affect deforestation rates in Brazil's Amazon and the greenhouse gas profile of the associated biofuels.

The paper is organized as follows. The next section offers a literature review of various modeling efforts for estimating land use change as well as provides an overview of the drivers and trends of deforestation in Brazil. The third section presents the modeling approach with a description of

[1] CARD/FAPRI: Center for Agricultural and Rural Development/Food and Agricultural Policy Research Institute at Iowa State University

the Brazil model including the newly developed forestry component. Then the implementation of the scenario is described followed by results and conclusions.

Literature Review

Modeling of land use change

Over the past several years, there have been a number of policy initiatives relating to biofuel production as a means of helping control the carbon dioxide levels of the Earth's atmosphere. In an effort to guide policymakers, numerous studies have attempted to quantify the link between biofuel policy and these carbon dioxide levels. This section summarizes the assumptions of key parameters used in recent modeling efforts of indirect land use change resulting from U.S. and Brazilian biofuel policies.

Although not the first to link biofuel production and land use change, papers by Searchinger et al. (2008) and Fargione et al. (2009) were the first to bring attention to the need for proper accounting of the carbon costs of converting land to biofuel production. This involves quantifying the impact of indirect land use changes, i.e., changes brought about from biofuel expansion induced crop price increases. To understand the impact that these price changes will have on land use, it is important to understand the balance between increased production brought about by intensification (yield enhancement) and by extensification (area expansion). The yield price-elasticity relative to the land price-elasticity is what is important. If, for instance, acreage response is high and yield response is low then an increase in price induced by biofuel expansion will lead to greater land conversion than if the yield response is high relative to the acreage response. Additionally, to fully understand the balance between the two margins, how the yields of newly converted lands are modeled needs to be considered.

Yield Price Response

In most empirical work, yield adjustments are modelled as a function of time. This implicitly assumes that yield changes are entirely due to technological advances, thereby assuming that yield is independent of a crop's market. There have been a number of studies, however, that have attempted to disentangle price response from technological growth. One paper is by Searchinger et al. (2008), which assumes that any increase in yields due to higher crop prices will be offset by lower productivity of lands converted to crop production. This assumption has three key components: yield response and acreage response are both positive and newly converted lands are marginal lands, that is, their yield is lower than that of existing crop land. A summary of literature findings is provided in Table 1.

Table 1. Yield price-elasticities

Study	Region	Crop	Elasticity
Goodwin et al. (2012)	Illinois, Indiana, Iowa	Corn	0.19-0.27
	Illinois	Corn	0.43
	Indiana	Corn	0.15
	Iowa	Corn	0.28
Huang and Khanna (2010)	U.S.	Corn	0.15
	U.S.	Soybeans	0.06
	U.S.	Wheat	0.43

Keeney and Hertel (2009)	U.S.	Corn	0.25
Roberts and Schlenker (2009)	U.S.	Corn, Soybeans, Wheat, Rice	Negligible
Searchinger et al. (2008)	U.S.	All Crops	Negligible

Keeney and Hertel (2009) review some studies looking at yield price-elasticity estimates for corn. After ruling out three of the estimates as irrelevant, the authors average four of yield price-elasticity estimates for data ranging between 1951 and 1988. The authors arrive at an average yield price-elasticity of 0.25.[2] However, Berry (2011) argues that the time series evidence from U.S. data does not support a significant yield response to prices. Roberts and Schlenker (2009), consider corn, soybeans, wheat and rice simultaneously. The authors note that crop prices are highly serially correlated over time and, if yields are driven by prices, that they too will be serially correlated. Finding no statistically significant serial correlation, they conclude that yields are driven by weather and not prices. They then argue that through inventory levels and storage, current demand is linked to the past weather (yield) shocks and this provides a means to exogenously shift demand and trace out current supply. Using standard two-stage least-squares they reach a total supply elasticity estimate between 0.105 and 0.106, which is entirely the acreage response.

While Roberts and Schlenker (2009) argue for negligible yield response, Huang and Khanna (2010) find a positive yield response. The authors incorporate the past weather shocks used in Roberts and Shlenker (2009), along with other instrumental variables, into a dynamic panel generalized method of moments estimation and arrive at yield price-elasticities of 0.15 for corn, 0.06 for soybeans, and 0.43 for wheat.

Goodwin et al. (2012) examine whether there is an intra-seasonal yield response to price changes early in the growing season within a portion of the Corn Belt (Indiana, Illinois, and Iowa). They conclude that there is a small but statistically significant response of yields to price changes early in the growing season. Goodwin et al.(2012)'s findings suggest a long-run yield price-elasticity of U.S. corn ranging from 0.19 to 0.27 for the aggregation of Illinois, Indiana, and Iowa and an elasticity ranging from 0.15 to 0.43 at the state level. This is in line with the estimate of Keeney and Hertel (2009), yet the authors have suggested that general equilibrium models such as the GTAP framework should use a yield price-elasticity greater than 0.25 because of the range of the state-level elasticities.

Generally speaking, the literature does not provide any consensus in regards to the magnitude of an appropriate yield price-elasticity and the existing evidence varies by econometric technique. Holding the level of aggregation constant, least-squares estimates tend to find an elasticity of larger magnitude than those from an instrumental variable estimation. High levels of aggregation such as the national level (or an estimate which includes all crops) tend to have estimates near zero regardless of the estimation method.

Acreage Price Response

[2] Keeney and Hertel (2009) reviewed Houck and Gallagher (1976), Lyons and Thompson (1981), and Choi and Helmberger (1993) and deemed the estimates by Houck and Gallagher (1976) and Menz and Pardey (1983) as irrelevant because they "incorporate a non-linear trend variable calibrated to adoption patterns (of high yielding varieties) observed in the mid-20th century."

While yield response has been the primary research area of recent years, acreage response is also necessary to understand land use change impacts of biofuel policies since the yield response relative to the acreage response is important. In the GTAP modeling framework used by California Air Resources Board (CARB), a Constant Elasticity of Transformation (CET) supply function is used to determine how land moves between uses. More recently, the GTAP-AEZ framework includes agro-ecological zones as a means of disaggregating regions to more accurately estimate land use changes. How the land change uses within a given region is ultimately dependent on the elasticity of land transformation driving the CET functional form. Ahmed, Hertel, and Lubowski (2008) show how U.S. cropland supply elasticities are used to calibrate the elasticity of land transformation. The results of this calibration are that the own-return elasticities of land use rise as the term of analysis expands over time, beginning around 0.05 for U.S. crops, 0.22 for U.S. pasture, and a negligible amount for U.S. forestry.

Barr et al. (2011) argue that the elasticity estimates used by CARB are out of date. They take advantage of the dramatic climb in prices in 2007 in the U.S. to determine an aggregate land price-elasticity for the U.S. Similarly for Brazil, they take advantage of the acreage differences between recent boom and bust years to arrive at an aggregate land price-elasticity. For the U.S., they use two methods to calculate the aggregate land price-elasticity. The first is using 3-year averages of acreage and expected returns for both the pre-boom years (2003-2005 or 2004-2006) and the boom years (2007-2009) and using the percent change in acreage and expected returns to find the elasticity. The second is to use a linear trend to forecast what 2007-2009 would have looked like and comparing that to what actually occurred. Then, holding costs and expected yields constant, they are able to estimate the elasticity of expected net returns with respect to price to convert the land net returns-elasticity to a land price-elasticity. Their results vary between 0.007 and 0.029 for the U.S.

Using similar techniques but different time periods, the authors arrive at estimates for Brazil ranging from 0.38 to 0.477 in recent years. This Brazil estimate indicates potentially large movements of carbon-rich forestry into cropland so the authors also calculate Brazil's elasticities with a pasture component included in the model and find that the elasticities now range between 0.007 and 0.082. This suggests that additional lands would come primarily from pasture and not forests.

A paper by Huang and Khanna (2010) uses two models to estimate acreage response in the U.S. The first includes lagged acreage, weather, input and output prices, population density and a time trend. The second also includes price and yield risk variables. Across these two models, the results are robust and provide acreage elasticities for total crop, corn, soybean, and wheat of 0.26, 0.51, 0.49, and 0.07, respectively. They also find evidence that current crop acreage is positively related to the acreage in previous years. This supports the idea that there is a slow transition in land use. Although Huang and Khanna provide estimates of total crop acreage response that are much higher than those used by CARB, it is one of the few recent papers to provide crop-specific acreage elasticity estimates. Table 2 provides the land price-elasticity estimates from a number of different studies.

Table 2. Land price-elasticities

Study	Region	Crop	Elasticity
Ahmed, Hertel and Lubowski (2008)	U.S.	Crops	0.05
	U.S.	Pasture	0.22
	U.S.	Forests	Negligible
Barr et al. (2011)	U.S.	Crops	0.007-0.29
	Brazil	Crops (w/out pasture component)	0.38-0.9
	Brazil	Crops (with pasture component)	0.007-0.245
FAPRI (2004)	Brazil	Crops and pasture	0.13
Huang and Khanna (2010)	U.S.	Corn	0.51
	U.S.	Soybeans	0.487
	U.S.	Wheat	0.067
	U.S.	Crops	0.257
Lin and Dismukes (2007)	U.S.	Corn	0.17-0.35
	U.S.	Soybeans	0.3
	U.S.	Wheat	0.25-0.34

Yield Response to New Land

While it is the relative elasticities that matter in determining land use impacts of biofuel driven price increases, inherent in the magnitude of land conversion are the yields of these newly converted lands. In Searchinger et al. (2008), the assumption is that the yield drag of newly converted lands would offset the yield gains on the intensive margin. Despite its importance, surprisingly little research has been made in this area.

Lywood, Pinkney, and Cockeril (2009) comment on the relative importance of yield drag in given regions. They state that total output growth in the U.S. and the EU is primarily due to yield growth whereas in most other countries 60 percent or more of the output growth is due to an increase in acreage. One possible explanation for this follows from Keeney (2010) in which he compares the area and yield growth in various countries. The conclusion he reaches is that the evidence of a significant yield drag in a particular nation depends on that nation’s distance from the technological frontier for the given crop. The data for Canada, for instance, shows a distinct inverse relationship between maize area and yield. On the other hand, Brazil shows no such relationship. It is therefore very important to regionalize assumptions when modeling indirect land use impacts. Brazil, in particular, had tremendous growth in corn yields and area following the Uruguay Round reform in 2000. This indicates a pattern of technological development that makes both the yield price-elasticity as well as the yield drag of newly converted lands difficult to estimate since the effects of incorporating new technologies would overshadow price responses or the ability to compare marginal and average yields.

As the technology gap between Brazil and the U.S. continues to close, yield drag may be more apparent. For the time being, data on the trend in the United States and other developed nations indicates that the yields of newly converted agricultural lands will be lower than those of existing lands. In regards to the importance of the yield drag in Brazil, Keeney uses the GTAP framework to provide a sensitivity analysis of Brazilian land conversion to the yield price-elasticity and the ratio of marginal to average yields. Figure 1 shows that, for a given yield price-elasticity, the effect of biofuel expansion on land conversion varies significantly depending on how yield drags are modelled (the values in the bubbles represent millions of hectares converted to cropland when the U.S. institutes a 15-billion-gallon increase in corn ethanol demand).

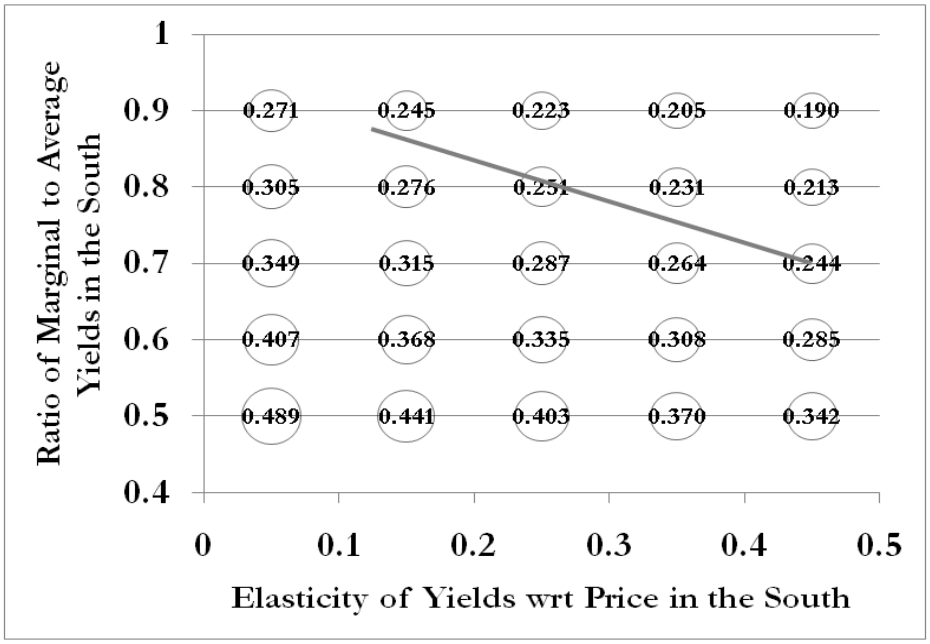

Figure 1. Sensitivity of Brazilian land conversion to yield parameters
Source: Figure 10 from Keeney (2010)

Over the past decade, attempts have been made in both the GTAP framework and the FAPRI Brazil model to disaggregate the models into different regions. GTAP, for instance, has disaggregated Brazil into agro-ecological zones while the FAPRI Brazil model has disaggregated Brazil into different regions. These attempts are meant to better judge the productivity of different regions in a given activity, as well as to have a better match between activities, and ecosystems affected.

Following Keeney (2010), the GTAP framework assumes that the productivity of new lands converted to crop production is about two-thirds of the average productivity of existing croplands. This two-thirds assumption follows from the average of literature estimates of the ratio of marginal to average yield of different U.S. crops. The FAPRI Brazil model similarly uses a yield drag of newly converted lands but this yield drag is regionalized.

Drivers and Trends of Deforestation in Brazil

Drivers of Deforestation

According to a review conducted by Nassar, Harfuch, and Granco (2013), the list of direct drivers of deforestation in Brazil is long (see Table 3) but has changed significantly over time.[3] During the 1980s, the deforestation rate was approximately 21,000 km^2 per year. The main drivers were human colonization, the development of infrastructure, and lower land values leading to increased grazing by livestock. The livestock sector is responsible for about 80 percent of total deforested area. Other drivers included government subsidies, unclear land tenure, and policies promoting land speculation. With higher land values, and despite increased logging and livestock grazing in the 1990s, deforestation rates decreased by about 20% relative to the 1980s. The later part of the 2000s experienced a further decrease in deforestation coinciding with volatility in commodity markets as well as stricter regulations on deforestation and improved monitoring and enforcement. Nonetheless, 14 percent of total deforestation was legal and authorized in 2000. Until 2008, deforestation totaled 70.5 million hectares (17.5 percent of total area in the Brazilian Amazon) (Nassar, Harfuch, and Granco, 2013). Table 3 presents conclusions from several studies on the main direct and indirect drivers of deforestation in Brazil.

As Table 3 indicates, the studies point to a number of variables including paved and unpaved roads (infrastructure), agricultural expansion (livestock and crop production), accessibility to markets, population and migration, and wood extraction. In the early 1990s, about 74 percent of deforestation resulted from the construction of infrastructure networks. In addition to their primary function, road expansions facilitated deforestation practices, illegal occupation of land as well as land tenure conflicts. Deforestation from building more roads is not likely to continue to be a main driver in the future as Brazil is concentrating more on infrastructure improvements rather than expansions. Another main driver, rural settlements resulting from agrarian reform policies in the 1970s, may be linked deforestation at least in the period between 1995 and 2009, when the area of rural settlements and the rate of deforestation increased significantly in the Amazon region. Fifteen percent of total deforested area in the Amazon region can be attributed to rural settlement areas (Nassar, Halfuch, and Granco, 2013). Soybean expansion is another main driver.

In addition to the direct drivers of deforestation, Nassar, Harfuch and Granco (2013) looked at the impact of indirect land-use change on deforestation. While they cite studies that indicate links between biofuel expansion and deforestation, they point to the limitations of current modeling efforts of land-use change in isolating the impacts of biofuels.

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[3] In this section, we rely primarily on the work by Nassar, Harfuch, and Granco (2013), which is an integral part of the cooperative research between CARD, USDA and ICONE, Brazil on which this paper is based.

Table 3. Main Deforestation Drivers

Study	Main Direct Drivers
Angelsen and Kaimowitz (1998)	Roads; higher agricultural prices; lower wages; shortage of off-farm employment
Margulis (2003)	Large and medium livestock producers
Aguiar, Câmara and Escada (2007)	Proximity to urban centers and roads reinforced by the higher connectivity to the more developed parts of Brazil Higher impact on deforestation and pasture extent in areas in which the land structure is dominated by large and medium farms Temporary and permanent agriculture patterns concentrated in areas where small farms are dominant
Faminow (1997)	Market driven cattle sector expansion in Amazon; growth of population and the resulting growth in demand
Kirby et al. (2006)	Paved road as well as unpaved roads; urban and rural population
Almeida et al. (2007)	Accessibility to market, demographical and political categories (when Euclidean distance to nearest road is included, the demographical category loses it explanatory power)
Diniz and Oliveira Junior (2009)	Bidirectional causality between deforestation and the agricultural sector (cattle herd/pasture, permanent and annual cultures, agriculture and pasture area) as well as socio-economic characterisitcs
Martins et al. (2010)	Livestock production and population density; in the medium and high category, production of permanent crops and temporary crops
Study	**Main Indirect Drivers**
Arima et al. (2011)	Reduction in soybean field expansion in the settled agricultural area yields a decrease in frontier deforestation
Barona et al. (2010)	Pattern of deforestation seems to be related to changes in pasture area in the interior Amazon
Macedo et al. (2012)	Possible to have an increase of production and forest conservation if there is sufficient supply of previously cleared land; deforestation for cropland in Mato Grosso remained low even when profitability favored soybean expansion; Mato Grosso's reduction of deforestation after 2005 did not direct leakage of soybean into Mato Grosso's Cerrado or adjacent Amazonian states
Lapola et al. (2010)	Direct deforestation only caused by soybean biodiesel; sugarcane ethanol and soybean biodiesel responsible for 41% and 59%, respectively, of indirect deforestation of Amazon Forest and Brazilian Cerrado; ILUC can be much lower or even zero with different assumptions on cattle intensification.
Ferreira Filho and Horridge (2011)	For each new sugarcane hectare, 0.14 hectares reduction in unused land (converted in the agriculture frontier), and 0.47 hectares reduction in pastures; higher agricultural productivity has a positive effect
Nassar et al. (2011b)	The indirect effect is less than proportional with respect to the expansion of sugarcane area—total agricultural land expanded by less than the increase in the sugarcane area

Source: Table adapted from Nassar, Halfuch, and Granco (2013)

Trends of Deforestation

The Amazon, which is the largest biome with a total area of 5 million km^2, has approximately 1.1 million km^2 of protected areas. Sixty-three percent of the protected area in the Amazon is public forest with sustainable use while the rest is strictly protected without any use allowed (with some indigenous reserves). The remaining 4.9 million km^2 is divided between mostly natural vegetation, anthropized areas, and water (Nassar, Harfuch, and Granco, 2013). Land cover and land use are very different among the states in the Amazon.[4] Pasture uses comprises the largest share of total area in the state of Rondônia (almost 30 percent) while the largest use of pasture is in the states of Mato Grosso and Pará. In Mato Grosso, annual crop production represents 87 percent of the total area allocated to annual crops in the region.

Figure 2 shows the historical patterns of the Amazon deforestation over time. Deforestation rates fluctuate considerably for many reasons including legislation. Two important pieces of legislation in 1989, Legal Reserves aimed at registering and conserving parts of the Amazon, and Permanent Preservation Areas establishing buffer zones around water bodies and steep slopes, helped decrease deforestation rates in the 1980s. However, 1995 witnessed significant levels of deforestation prompting the Brazilian government to stronger restrictions on deforestation in 1996. In 1998, the Environmental Criminal Law imposed stiff fines and imprisonment for crimes against fauna and flora as well as for pollution and other environmental crimes. However, there were difficulties enforcing the law. Deforestation rates increases significantly again in 2004, the Brazilian government launched PPCDAM (Plano de Ação para a Prevenção e Controle do Desmatamento na Amazônia Legal), which led to stricter enforcement against environmental crimes and corruption, as well as incentives for sustainable environmental practices. As a result, deforestation rates decreased noticeably between 2004 and 2007. Additionally, the "Soybean Moratorium" and the "Livestock Moratorium" were established in 2006 and 2009, respectively, by major producers with a commitment not to include in the supply chain any products coming from deforested areas of the Amazon biome. More recently, the National Policy of Climate Change (PNMC) in 2009 and the new Forest Code in 20011, are expected to further reduce deforestation rates over time. PNMC aim is to reduce deforestation rates to 3900 km^2 by 2020. Rates have dropped significantly compared to the early 2000s because of the effective initiatives to reduce deforestation.

[4] The Brazilian states located in the Amazon biome include Acre, Amazonas, Amapa, Maranhao, Mat Grosso, Para, Rondonia, Roraima, and Tocantins.

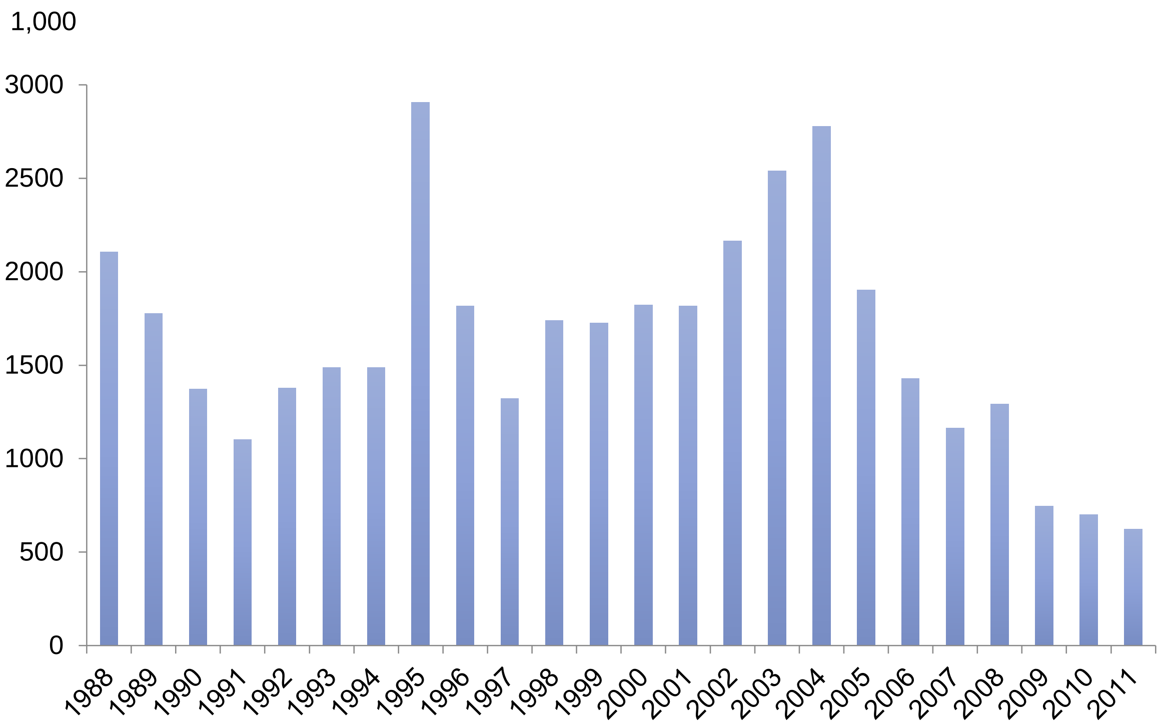


Figure 2. Historical patterns of Amazon Deforestation
Source: Nassar, Halfuch, and Granco (2013)

After deforestation, soybean production, livestock activities and timber production are cited as the main uses of land. The expansion of soybean production has impacted deforestation differently across time. In the early 2000s, soybean area expansion came from pasture (76 percent) and forest (26 percent). In the later 2000s, because of productivity growth (yield increases), production increases and over 90 percent of area expansion came from pasture areas. Two-thirds of pasture area converted by soybeans was deforested before 2000.

In terms of livestock production, until 2006, deforestation rates and cattle herd variation were strongly correlated. However, after 2006, intensification in terms of higher stocking rates, carcass weight and slaughter rate, resulted in a decline in deforestation rates despite an increase in livestock production alongside an increase in crop production and commercial forests. The signing of the Livestock Moratorium by the major Brazilian beef companies as well effective public policies also aided in reduction of deforestation rates.

The expansion of ethanol has also been cited as a main driver in deforestation but during the 2000s period, sugarcane area expansion came mainly from displacing pasture area (74 percent) and crops (24 percent). Nassar, Halfuch, and Granco (2013) contend that the fact that the sharp expansion of sugarcane area occurred during a period (2005 to 2010) when deforestation rates were declining, indicates that there were no leakage effects from sugarcane expansion. They conclude that there is no direct effect of sugarcane displacing natural vegetation since sugarcane can only be produced in areas already anthropized. They also cite research that concludes that there are negligible indirect effects of expansion of ethanol production in the Amazon.

Modeling Approach

The analysis in this study is conducted through an augmentation of the well-established CARD/FAPRI modelling system, which has been widely used to evaluate and inform policy and regulatory issues. Here, we follow closely a description of the model presented in Elobeid, Carriqury, and Fabiosa (2012). After a general overview of the modeling system, we present in this section a detailed description of some features of the Brazil model, which is a component of this agricultural modeling system. The focus of the description is on Brazil as land use change implications and the new forestry component was introduced first for this country.

The CARD/FAPRI modelling system includes econometric, multimarket, non-spatial, partial equilibrium models covering all major temperate crops, ethanol, sugar, biodiesel, dairy, and livestock products for all the major producing and consuming countries. As shown in Figure 3, the modeling system allows for interactions among the different markets to capture the derived demands for feed in the livestock sector, feedstock in biofuel production, substitution possibilities between close substitutes, as well as competition for land. The modeling system is designed to provide ten to fifteen year projections of supply, utilization and prices for major agricultural commodities in major producing and consuming countries, running y yearly steps. The system solves for a set of prices that equate supply and demand for all commodities and in all countries modeled. For a more detailed description of the models, see Elobeid et al. (2011), and for references of studies that used this modelling system the reader is referred to Meyers (2010)

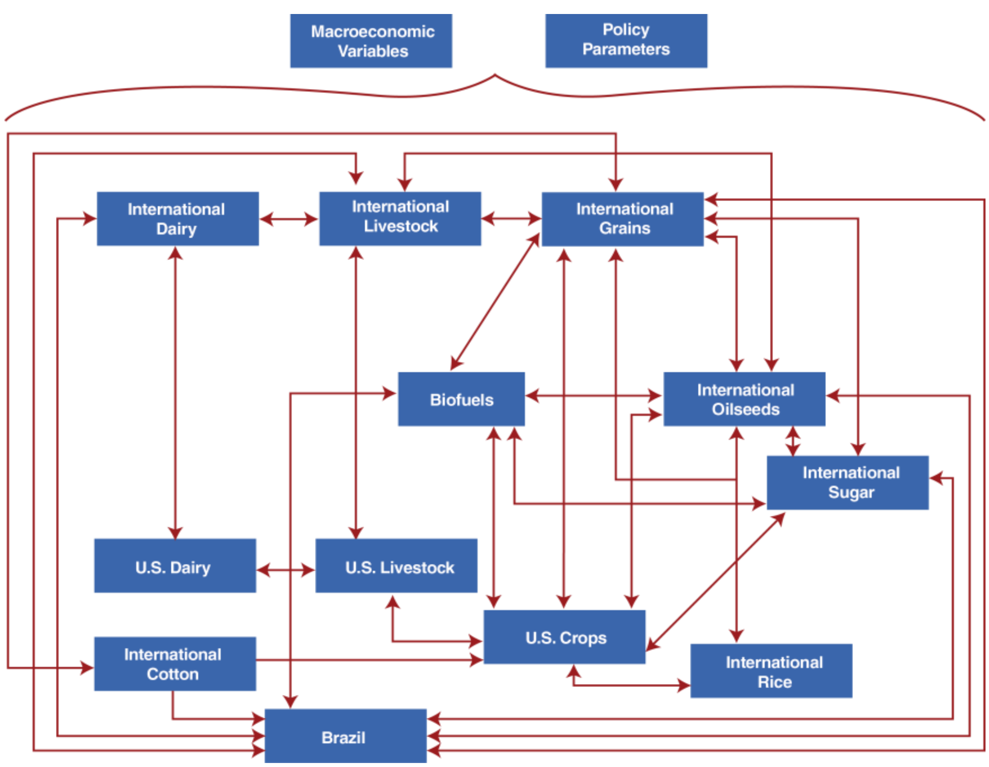
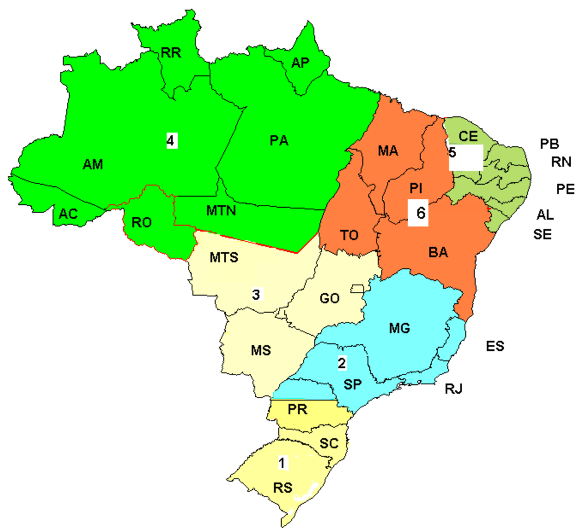


Figure 3. CARD/FAPRI Model Interactions

While most of the components (interacting boxes in Figure 3 represent models) within the system are commodity models, Brazil and the United States are the two country models, which are comprised of their respective integrated agricultural markets within each country. Given that Brazil has widely varying ecosystems, the Brazil model is divided into 6 regions to capture the regional differences in infrastructure and available natural resources for agricultural production. These regions are South, Southeast, Center West Cerrado, Amazon Biome, Northeast, and North-Northeast Cerrado (see Figure 4). The regions are modeled to reflect differences in capabilities and consequences of expanding agricultural production such that the impacts of land use changes derived from increasing demand for agricultural products can be more accurately analyzed.



Region 1: South

Rio Grande Do Sul; Santa Catarina; Parana

Region 2: Southeast

Sao Paulo; Rio de Janeiro; Espirito Santo; Minas Gerais

Region 3: Center West Cerrado

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 Cerrado

Tocantins; Bahia; Maranhao; Piaui

Figure 4. Regional Disaggregation of the CARD/FAPRI Brazil Model

As with the rest of the CARD/FAPRI models, the Brazil model includes all major crops, biofuels, and livestock interacting and competing for agricultural resources, in particular, land. The model provides 10-to-15 year projections of supply and utilization variables and the amount of land allocated to each of the activities considered. The crops include corn (first and second crops), the soybean 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 of 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. Spatially disaggregation of information on historical production activities and land availability, allows for the regional analysis the relative profitability of productive activities. The local profitability will drive regional supply curves for crops and livestock operations and their associated land use.

Within the Brazilian model, agricultural area and allocation it to land-using activities is performed following two different approaches. First, for crops not in direct compete for land resources, either because they do not occupy land during the main growing season, or they are spatially separate, behavioral equations that project agricultural area are used. Wheat, barley, the second crop of corn, and the second crop of dry beans fall into this category. For these crops land allocation equations are mainly driven by real relative returns of the different activities.

Alternatively, a second group of land using activities that compete for land resources in time and space. Land allocation for these activities is modeled using a two-step approach. The total area utilized for agricultural activities is determined first. As mentioned before, the CARD/FAPRI model was augmented for this model by the inclusion of a planted forestry component. While the next sections provide additional information regarding the specifics of this component, we mention here that the area allocated to planted forests is also determined at this stage, competing with land used for crops and pasture. An allocation of the area used for agriculture to the competing land uses is performed in a second step. Corn, soybeans, rice, cotton, dry beans, sugarcane, and pasture are modeled through this procedure. While the model solves for these steps simultaneously, it is clearer to present the procedures as if performed in steps.

In the first step, we determine the area to be used for agriculture and pasture in each region as a function of expected returns as follows:

$$A_{jt}^{ag} = A_j^T m_j \left(\overline{r}_{jt}, r_{jt,t+s}^{f} \right) \tag{1}$$

where $\overline{r}_{jt}$ denotes expected returns to land use (crops and pasture) in region *j* and year *t*, $r_{jt,t+s}^{f}$ are the expected returns to forestry in region *j* and year *t* discounted over a horizon of *s* years,[5] and $m_j \left(\overline{r}_{jt}, r_{jt,t+s}^{f} \right)$ is the share of the potential agricultural and forestry land $\left(A_j^T \right)$ that is used in that region and year. Expected returns evolve based on the area weighted average of the return growth of the different activities, as;

$$\overline{r}_{jt} = \overline{r}_{jt-1} * \sum_{i=1}^{I} \left(\frac{\tilde{A}_{ijt}}{A_{jt}^{ag}} \left(1 + \frac{r_{ijt} - r_{ijt-1}}{r_{ijt-1}} \right) \right), \tag{2}$$

[5] Additional details on the specification of the forestry returns and modeling strategy are provided in the next sections.

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. Holt (1999) proposed a framework that yields linear equations to share the are out the to the different activities. In this framework, the share of the total area asigned to a given activity $\left(\nu_{ijt}\right)$ is calculated as

$$\nu_{ijt} = b_{ij} + \sum_{i=1}^{I} s_{ij} * r_{ijt} \tag{3}$$

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

$$\tilde{A}_{ijt} = A_{jt}^{ag} * \nu_{ijt} \ . \tag{4}$$

In this framework, the own-price elasticity for the area dedicated to a crop can be calculated as the sum of a a scale effect and a competition effect as $\varepsilon_{ij} = \varepsilon_{ij}^{\text{scale}} + \varepsilon_{ij}^{\text{comp}}$. The scale effect indicates the change in area for a crop given a variation in total area as a result to that crop's change in returns. The second term captures the change in area as the the crop whose returns increase competes away land from other activities.. Further, we can show that the scale effect is $\varepsilon_{ij}^{\text{scale}} = \varepsilon_{r_j}^{Ag,j} * \varepsilon_{r_{ij}}^{r_j}$, where $\varepsilon_{r_j}^{Ag,j}$ is the elasticity of agricultural area to average expected returns to agriculture and $\varepsilon_{r_{ij}}^{r_j}$ denotes the elasticity of expected agricultural returns to the returns of activity *i*. The subscript *j* denotes the region.

In the spirit of the description being presented, the elasticities for agricultural activities (crops and pastures) vary both by activity and region, and the numbers used in the model are presented in Table 4. The Center West Cerrados and the Amazon area (North in the table)), present the highest responsiveness to changes in returns (as indicated by the first column), as a result in part of their relative land abundance. Regions with more severe land limitations, either because they were established earlier (and a higher proportion of the suitable land is already under production) or with resource constraints (more restrictive soils or climatic conditions) have lower area elasticities. As the table indicates, some crops such as soybeans and sugarcane are more responsive to changes in returns than staples for domestic consumption such as rice or in particular dry beans.

Table 4: Regional land-use elasticities and own-price elasticities for activities in Brazil model

Region	$\varepsilon_{r_j}^{Ag,j}$	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
Center 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 Cerrado	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.

Table 4 shows that the elasticities of pasture, differ (as is the case of crops) by regions, indicating that pasture based livestock activities (beef and dairy production) are regionalized. More broadly all supply side of the livestock sector (including poultry and swine production) is modeled at a regional spatial disaggregation. The modeling strategy varies by livestock activity. Specifically, poultry production is modeled through a behavioral equation depending on prices and costs of production and which vary by region. For beef, dairy, and swine, the evolution of the stocks of animals are tracked over time. Production levels are then consistent with the number of animals (and in the case of beef cattle on the stock composition) available. For example, through endogenous birthrates, and stocks of cows and sows, the numbers of calves and piglets are obtained. The stock of adult animals not part of the breeding herd are also tracked as part of the "other" category. The number of animals of each category, combine with a slaughter weight (by category) to project meat production numbers. Slaughtered animals and deaths are taken into account to track the evolution of the stock.

An important feature of the model is that allows for feedback between the pasture area and the size of the cattle herd. This is critical for internal consistency, as pasture is the major component in cattle diets, and at the same time cattle (and in particular beef) is the largest user of pastures. These feedbacks are modeled through the stocking rate (number of heads per hectare of pasture), which is dependent on profitability. Profitability of beef and crops will interact to determine the number of hectares of pasture following the land allocation mechanism described before.

We briefly outline some major features of the ethanol component of the Brazil model as it will help understand the responses to the scenario to be analyzed in this paper. In Brazil, sugarcane is the main feedstock for ethanol. The land allocation mechanism described above determines the area planted to sugarcane by region based on the expected returns to agriculture and relative returns of sugarcane versus that of other land competing activities. While there is no market price for sugarcane in the model, returns to this activity is calculated based on the prices of sugar and ethanol, and the concentration of recoverable sugars in the cane. This later fraction, which is the feedstock for sugar and ethanol production is then allocated (shared out) to each of these activities depending on their relative price.

A demand side is needed to close the market. Domestic demand (for transport) for ethanol is both in in anhydrous and hydrous forms. The anhydrous form is consumed in mandatory blends with gasoline (25% ethanol)., by both gasoline and flexible-fuel vehicles (FFVs). Hydrous ethanol is mainly used by FFVs but also by gasohol cars. Based on the relative price of these two fuels, FFV owners can choose between ethanol and blended gasoline. The domestic ethanol price follows the world price determined in the international ethanol component of the modeling system (which equated global excess supplies and demands), which is adjusted by exchange rates and border policies.

The Brazil Forest Model

For this study, we expanded the existing CARD/FAPRI Brazil agricultural model to include a forestry component. Beyond its previous capabilities to project land use changes associated to crops and pastures, the model can now be used to explicitly capture interactions between these sectors and the forestry sector. The land allocation component, capturing the competition between planted forests, crops, and pastures now jointly considers the expected returns of these activities to determine the amount of land that will be used as well as the distribution among these three uses.

Data for the forestry model was obtained from the Brazilian Institute for Geography and Statistics (IBGE) and the Brazilian Association of Forest Plantation Producers (ABRAF), for the 2004-2011 period. Data included areas of planted forests (eucalyptus and pines), production of cellulose and paper, domestic consumption, and exports of cellulose and paper. While supply side variables were obtained at the regional levels for geographic areas approximately matching those of the initial (not expanded) Brazil agricultural model, the demand side was modeled at the country level. Further, we modeled a single aggregate demand component, without distinguishing between products or source of demand (domestic versus exports).

Representative prices of forestry products were obtained by dividing their value of production by production. Extraction rates, or amount of wood harvested per unit of land were obtained by dividing the quantity of forestry products by the area under plantations. Trends were fit to these values in order to project the evolution of extraction rates (akin to yields) over time.

As for the modeling of crops and pasture, the area of planted forests is projected in terms of shares of the total land potentially available for agriculture and forest production. In particular, the share of land for forestry products is obtained based on the expected returns to forest production, and to other competitors for land (namely crops and pasture). The main difference with the previous version of the Brazil model (without forests) and other components of the CARD/FAPRI modeling system is that the decision to whether or not to allocate land to forests and other uses depends on a comparison of current returns to crops and pasture versus returns to forests which will not be obtained until several periods into the future. In particular, to allocate land in period *t*, the model compares current expected returns to crops and livestock against forestry returns that will only materialize in the future, the value of which will be discounted using an interest rate. Mathematically, the area allocated to planted forests is projected as

$$A_t^f = A^T f\left(r_{\mathrm{t},t+s}^f, \bar{r}_{jt}\right)$$

where A_j^T is the area potentially available for crops, pasture and planted forests, $r_{t,t+s}^f$ is the period t discounted returns to forest production to be obtained in period $t+s$, and $\bar{r}_{jt}$ represents expected returns to agricultural uses. The function $f(.)$ represents the share of available land that will be allocated to forestry production.[6]

In this line, expected supply and demand conditions for forestry products in the future (say in period $t+s$, with $s>0$) will affect the price of forestry products in period t, which will affect the competition for land with crops in that period. At the same time, the price for forestry products in period $t+s$ needs to clear the market for these products in that year. Through an iterative process, the model solves for prices for agricultural and forestry products for every year of projection, using the forward looking mechanism described for forestry.

Scenario Description and Results

Scenario Description

For the scenario, we shock the demand for ethanol in the U.S. with a 15 percent exogenous (and permanent) expansion. In order to analyze the impact of the increase in the demand for U.S. ethanol on Brazil, we first establish a baseline (business-as-usual scenario) against which the high U.S. ethanol demand scenario is compared.

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 then be transmitted to the markets of 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 can be 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.

[6] *f(.)* was specified as a constant supply elasticity function.

Results

Impact on the U.S. Agricultural Sector

The U.S. Ethanol Sector

Table 5 presents the change in U.S. ethanol production, consumption, trade and prices for the year 2021/22, which is the last year of projections. The higher demand for ethanol increases ethanol wholesale prices by 3 percent (and ethanol retail prices by 34%) relative to the baseline, which results in an increase in ethanol production by almost 17%. Because of the increased ethanol supply, gasoline retail prices decline by almost 3% relative to the baseline. The small increase in net imports of ethanol in the U.S. reflects the fact that the higher demand for ethanol is met by increased domestic production rather than increased imports.

Table 5: Change in U.S. ethanol production, consumption, trade, and prices in 2021/2022

	Baseline	Scenario	Percent change from baseline
		(Million gallons)	
Production	17,009	19,871	16.8%
Disappearance	19,093	21,957	15.0%
Conventional	14,842	17,691	19.2%
Cellulosic	900	900	0.0%
Other advanced ethanol	3,352	3,366	0.4%
Net trade*	-2,090	-2,098	0.4%
Ending stocks	954	1,093	14.6%
PRICES		(Dollars/gallon)	
Ethanol, FOB Omaha	2.25	2.32	3.3%
Unleaded gasoline, FOB Omaha	2.50	2.50	-0.1%
Unleaded gasoline, retail	3.26	3.17	-2.7%

* Positive values indicate net exports while negative values indicate net imports.

The U.S. Grain Sector

Table 6 shows the impact of the increased demand for ethanol on the U.S. grains sector. The higher demand for ethanol increases the demand for corn used in the production of ethanol. U.S. corn used for ethanol goes up by 18% resulting in 3% increase in the price of corn. In response to the higher corn prices, domestic corn production goes up by 3% (a 3% increase in area harvested). Total use increases by about 7% because higher corn prices reduce feed (by almost 4%), and food and other uses (by 0.3%). There is a significant reduction in the net exports of corn.

Table 6. Changes in U.S. corn, wheat and barley production, use, trade, and prices in 2021/2022

	Baseline	Scenario	Percent change from baseline
		(Million bushels)	
CORN			
Production	14,264	14,706	3.1%
Use	12,111	12,906	6.6%
Feed and residual	5,080	4,882	-3.9%
Fuel	5,519	6,517	18.1%
Food and other	1,511	1,507	-0.3%
Net trade*	2,196	1,821	-17.1%
Ending stocks	1,085	1,116	2.9%
WHEAT			
Production	2,138	2,124	-0.7%
Use	1,281	1,290	0.7%
Feed and residual	162	172	6.1%
Food and other	1,119	1,118	-0.1%
Net trade*	858	837	-2.4%
Ending stocks	863	853	-1.1%
BARLEY			
Production	195	197	1.0%
Use	193	193	0.2%
Feed and residual	29	30	3.1%
Food and other	164	163	-0.3%
Net trade*	2	4	69.4%
Ending stocks	61	61	-0.8%
		(Dollars/bushel)	
FARM PRICE			
Corn	5.59	5.78	3.4%
Wheat	6.69	6.80	1.5%
Barley	5.26	5.39	2.4%

* Positive values indicate net exports while negative values indicate net imports.

Higher corn prices and the increase in corn area by 3% bids land away from wheat, resulting in a decline in wheat area and production by 0.7%. Lower wheat supplies increase the price of wheat by 1.5%, which results in a reduction in food use, stocks and net exports. Feed use increases by 6% as wheat feed becomes relatively less expensive relative to corn, despite the higher wheat prices. Similarly, in the case of barley, the demand for barley feed increases by 3% and the price of barley increases by over 2%. The higher barley prices result in a decrease in food and stocks. In contrast to wheat, the area of barley increases as it does not face such strong competition (because of regional differences) for land from corn production.

The U.S. Soybean Sector

Table 7 presents the main impacts on the US soybean sector and its products. As in the case of wheat, the increase in corn area comes at the expense of soybean harvested area, which leads to a 1.4% reduction in the production of soybeans. Soybean price increases by 5% while use declines by 1%. Lower soybean supplies and a higher price lead to a 1% reduction in crush (due to lower crush margins) and a concomitant decline in the production of soybean oil and soybean meal.

Table 7. Changes in U.S. soybean production, use, trade, and price in 2021/2022

	Baseline	Scenario	Percent change from baseline
SOYBEANS			
		(Million pounds)	
Production	3,591	3,541	-1.4%
Use	2,078	2,047	-1.0%
Crush use	1,912	1,892	-1.0%
Other use	156	154	-0.9%
Net trade*	1,515	1,489	-1.7%
Ending stocks	217	212	-2.5%
		(US dollars per bushel)	
Price**	11.80	12.43	5.30%
SOYBEAN OIL			
		(Million pounds)	
Production	21,830	21,608	-1.0%
Domestic use	19,048	18,720	-1.7%
Net trade*	2,775	2,868	3.4%
Ending stocks	2,199	2,190	-0.4%
		(US cents per pound)	
Price***	56.64	57.03	0.7%
SOYBEAN MEAL			
		(Thousand tons)	
Production	45,407	44,946	-1.0%
Domestic use	35,662	34,921	-2.1%
Net trade*	9,739	10,019	2.9%
Ending stocks	331	331	0.02%
		(US dollars per ton)	
Price, 48% protein***	287.03	286.90	-0.05%

*Positive values indicate net exports while negative values indicate net imports; ** Illinois processor; *** Location: Decatur

Impact on the World Agricultural Sector

Table 8 shows the impact of the U.S. increased demand for ethanol on the world markets. The table presents the percent change in world prices for ethanol, sugar and major crops, as well as the global change in area harvested of these crops. Given that the higher U.S. demand for ethanol is met domestically, the impact on the world is muted especially in the case of sugarcane area and sugar prices. The increased (derived) demand for corn by the U.S. increases the world corn price by almost 4% and increases corn area harvested in the world by 1.3%. As corn area increases, this comes at the expense of area allocated to other crops, which decreases by 0.4% for soybeans and by 0.1% for both wheat and barley. As a result of the reduced supply, the prices of these crops increase relative to the baseline.

Table 8: Change in prices and areas of selected commodities in 2021/2022

	Price change	Area change	
	%	(1000 hectares)	%
Ethanol	0.2%	-	-
Sugar	0.1%	-	-
Sugarcane	-	-0.004	-0.01%
Corn	3.6%	2,161	1.3%
Soybeans	1.1%	-450	-0.4%
Wheat	1.3%	-220	-0.1%
Sorghum	1.9%	-10	-0.02%
Barley	1.7%	-77	-0.1%

Impact on the Brazilian Agricultural Sector

Brazil responds to the higher world prices by increasing area and production for corn, soybeans and wheat. The area expansion can be attributed to the need to partially replace the decrease in supply (exports) from the U.S. Ceteris paribus, the generated excess demand for the rest of the world will push crop prices up and increase crop area in Brazil. Sugarcane area and sugar production in Brazil increase slightly in response to the small increase in the world ethanol and sugar prices (see Table 8). The regional distribution of the change in crop area, pasture and planted forest is presented in Table 9.

Table 9: Regional changes in the area used for agriculture in Brazil in 2021/2022

Region	Sugarcane	Other 1st Crops[a]	2nd Crops[b]	Area Planted	Pasture	Forest	Area Used
	(1)	(2)	(3)	(4)=(1)+(2)+(3)	(5)	(6)	(7)=(4)+(5)+(6)-(3)
				(1000 hectares)			
South	-0.2	40.1	28.3	68.2	-37.9	-0.01	2.0
Southeast	-1.1	21.5	-0.4	20.1	-17.3	-0.05	3.1
Central West	1.6	70.6	76.3	148.5	-31.5	-0.03	40.7
North	0	22.0	13.5	35.4	-20.8	-0.03	1.2
Northeast Coast	0.2	6.8	0.0	7	-6.0	0.00	1.0
Northeast Cerrado	-0.1	28.1	3.3	31.4	-26.8	0.00	1.3
Brazil	0.4	189.1	121.1	310.6	-140.2	-0.12	49.2

[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.

Most of the increase in sugarcane area is in the Central West, which increases sugarcane area by a little over 1,000 hectares, an increase of 0.2%. In terms of the other crops, which include corn, soybeans, cotton, rice and dry beans, the largest increase is also in the Central West region with an increase of 71 thousand hectares. The total area planted to first crops increases by 189 thousand hectares. Similarly, the total area planted to second crops also increases, by 121 thousand hectares. While total area increased by 311 thousand hectares, only 49 thousand hectares more are used for agriculture (including crops, pasture, and planted forests). Table 9 indicates that some of the area expansion comes from pasture and forestland, which partially offsets the demand for additional land. The increase of cropped area into pasture is accommodated or feasible due to 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 10. The largest levels of pasture-use intensification can be observed in the South region. In short the possibility to substitute planted forests, and to intensify pasture based activities has the potential to reduce the levels of deforestation in the presence of high demand for crop land. While the change in stocking rates seem small, the sheer size of the pasture areas of the country imply that this is enough to accommodate the production of a nontrivial amount of beef.

Table 10: Change in the stocking rate of pastures (stock of cattle divided by pasture area) by region in 2021/2022

Region	Change in stocking rate
South	0.25%
Southeast	0.07%
Central West	0.06%
North	0.06%
Northeast Coast	0.04%
Northeast Cerrado	0.08%
Brazil	0.08%

Conclusions

This paper provides a review of several of the major factors that will determine the need to incorporate additional land to production in response to a demand increase, for example as a result of biofuel policies. This additional land that may need to be brought into production is critical as it will affect significantly the environmental credential and in particular carbon footprints of different biofuels. Among the factors reviewed are the potential for yield intensification in response to higher returns (intensification effects), and the limited existing evidence in yield drags as areas are incorporate to crop production (extensification effects).

In addition, the paper conducts a review of the recent trends on Amazon deforestation, highlighting the recent interventions and seemingly sustained lower rates than in earlier years. These lower rates, which may be the results of more stringent regulations and control, occur in a period of high agricultural price and demand for land, which calls for some additional research on the direct link between global agricultural demand and deforestation of the Brazilian Amazon.

Scenario analysis using an augmented version of the CARD/FAPRI agricultural modeling system (augmented to include planted forests in Brazil) seem to provide evidence in favor of the hypothesis of the previous paragraph. The potential for intensification of crops and livestock production in countries like Brazil, and of competing with planted forests reduces the pressure for deforestation of natural areas. We also highlight that the explicit modeling of planted forests as a user of land, allows for the inclusion of the competition of this activity (and its resistance to give away area) with the more traditionally modeled crops and pastures. The scenario included here was intended simply as an illustration. Work in this line is incipient and clearly more research is needed to truly understand the implications of adding this competition, different levels of policy enforcement, and potentials for yield (both in terms of crops and pastures) increases on evaluations of agricultural price change, land use change, and environmental impacts.

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