A PROSPECTIVE ANALYSIS OF BRAZILIAN BIOFUEL ECONOMY: LAND USE AND INFRASTRUCTURE DEVELOPMENT

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Abstract

The complex biofuel policy climate in Brazil, the U.S. and other countries leave the public with unclear conclusions about the prospects for biofuels supply and trade. In this paper we develop a spatial partial equilibrium framework regionally disaggregated for the agricultural and fuel sectors of the Brazil, U.S. and Argentina. The model considers the agricultural and fuel, including markets of China and the ROW in an aggregated way to analyze the impacts of the U.S. and Brazil biofuels blending mandates on those economies. However, special emphasis is given to the land use changes, economic welfare and total GHG emissions in the U.S. and Brazil. We focus particularly on the potential for livestock intensification in Brazilian pasture grazing systems as a prospective pathway for releasing new croplands and the impact of transportation infrastructure on fuel prices, ethanol production, consumption and trade. We find that intensification will dominate the land conversion process in Brazil rather than deforestation and savannah conversion, which ultimately implies reduced GHG emissions. We also find that development of three pipeline projects in Southeastern Brazil will lower the fuel prices and increase consumption slightly due to the reduction in costs of transporting ethanol from inland regions to major consumption areas and export outlets.

Keywords: biofuel economy, livestock intensification, land use change

Biofuel use has been considered as part of the solution to mitigate global greenhouse gas (GHG) emissions and to achieve energy security in many fossil-fuel importer countries. The U.S. and Brazil are the world's first and second largest biofuel producing countries, respectively. Historically Brazil has been the biggest biofuel exporter until 2010, while the U.S. was the largest importer. In the past two years the U.S. started exporting some corn ethanol to Brazil as a result of the excess supply in the U.S. and shortage of ethanol supply in Brazil. The latter was mainly because of the high sugar prices in global markets in the past few years which motivated sugarcane processors to convert more of the sugarcane supply to sugar which was previously half and half. The current trend in the international sugar and ethanol markets is likely to be temporal and Brazil may regain its leader role in supplying ethanol to the world markets in near future ethanol.

The U.S. introduced the Renewable Fuel Standard (RFS) as a fuel policy first in 2005 and revised it later by the Energy Independence and Security Act of 2007. RFS mandates blending 136 billion liters (Blt) of biofuels by 2022, of which about 80 Blt must be 'advanced biofuels', defined as biofuels with at least 50 percent GHG emission reduction relative to the emissions from fossil fuels they replace. Furthermore, the RFS requires blending oil-based fuels with at least 61 Blt of biofuels produced from cellulosic biomass (EPA 2010). Sugarcane ethanol is considered as an advanced biofuel since it reduces the GHG emissions by 60% relative to gasoline. As part of the incentives to increase national production, until 2011 the U.S. government imposed tariffs on the sugarcane ethanol imported from Brazil and provided subsidies for ethanol blenders and cellulosic ethanol producers. However, recently the tariff and subsidy provided to corn ethanol producers have been removed which may make sugarcane ethanol an economically advantageous biofuel compared to corn ethanol.

A third major player in the international ethanol markets is the European Union (EU). In 2008 the EU approved the Renewable Energy Directive (RED) along with a certification program to achieve a minimum 10 percent biofuel blending mandate by 2020. According to the OECD-FAO (2011) projections the EU may need to import more than 2.4 Blt of ethanol annually by 2022. Sugarcane ethanol meets the EU's standards with respect to GHG emission reduction (35 to 50 percent) and also complies the sustainability criteria.

Another important ethanol importer country is Canada which has a 5 percent blending mandate for gasoline. Currently Canada imports more than 1.1 Blt of corn ethanol from the U.S. which makes this country the second largest destination (after Brazil) of the U.S. ethanol exports.

Finally, China will play a significant role in the international biofuel markets due to the implementation of the 10 percent blending mandate into gasoline in the five most densely populated provinces and the 15 percent target for non-fossil energy consumption by 2020 in twenty seven cities (Bean, Scott, and Junyang 2011). According to Araújo and Lu (2010), these policies may lead to a 7 Blt deficit in 2020 which will make China the largest ethanol importer.

Brazil has implemented a mandate for blending anhydrous ethanol into gasoline, called gasohol, in the past four decades. Both conventional and flex-fuel cars can use gasohol, but the latter category, which is currently the dominating passenger car type, can use any blend ratio up to 100 percent hydrous ethanol (hereafter referred as E100). Another crucial fuel policy in Brazil is the tax rate applied to gasoline and ethanol, which is modified frequently to make E100 competitive with gasohol (Portal Brasil, 2011b). To complete the 'tool box' of Brazilian policy instruments, PETROBRAS, the main Brazilian oil refinery and domestic gasoline wholesaler (a semi-public company), has regulated the refinery price of gasoline during the past five years aiming to reduce the price volatility in the Brazil fuel markets (PETROBRAS, 2011).

This complex policy climate leaves the public with unclear conclusions about the prospects for biofuels; hence, several important questions are raised: If the ethanol mandates in the U.S., EU and China are enforced by 2022 would Brazil be able to fill their demand together with its increasing domestic demand for ethanol? Will the removal of the U.S. trade and subsidy policies make sugarcane ethanol imported from Brazil a more economical alternative compared to corn ethanol? If the U.S. modifies the RFS mandates what would be the economically optimum transportation fuel mix? How would the increased demand for sugarcane ethanol affect consumers' and producers' welfare, land uses in Brazil and U.S., and aggregate GHG emissions? Finally, if the current sugar market conditions and sugarcane productivity in Brazil continue, would the U.S. be able to substitute Brazil's role in the international biofuel markets?

Brazil has a vast amount of agricultural land most of which is used for beef cattle production using an extensive grazing system. It has been argued frequently that at a reasonable investment cost it is economically feasible to convert a substantial portion of those lands into cropland and expand the current sugarcane plantation to increase the ethanol production and meet the domestic and export demand for ethanol. Until now very little intensification has been realized, however several factors may stimulate the conversion of some pasture lands to crop land including i) the international biofuel mandates, ii) removal of the U.S. biofuel trade policies and subsidies provided to fuel blenders, iii) improvement in the Brazilian ethanol transportation infrastructure in particular the recently launched pipeline projects, iv) the continued change in the Brazilian vehicle fleet structure, and v) modifications in the Brazilian domestic fuel pricing policies.

In this paper, we develop a spatially explicit, multi-market, multi-product partial equilibrium framework to address the issues outlined above. This framework includes three major components: 1) a regionally disaggregated price endogenous model for the agricultural and transportation fuel sectors of the U.S. 2) a similar model for the agricultural and transportation fuel sectors of Brazil. Being a major supplier of corn, soybeans and wheat, which are likely to be affected by the above biofuel policies, and a competitor of the U.S. and Brazil in the global market we also integrate a regionally disaggregated model for the agricultural sector of Argentina including these three major crops. The model also includes an aggregate component for the food/feed and fuel commodity markets in China and a similar component for the Rest of the World (ROW), but unlike the U.S., Brazil and Argentina modules these additional model components include an aggregate demand and supply function for each of the three major agricultural commodities and transportation fuels. In the fuel sector component, following Chen et al. (2011), the model considers separate gasoline supply curves for U.S., Brazil, China, and the ROW. The main motivation is to capture the effects of biofuel policies on transportation fuel markets, and thus the demand for biofuels. The latter is derived from an explicitly specified driving demand behavior of consumers and the technological relationship between fuel consumption and miles/kilometers generation and substitution possibilities between alternative fuels. The choice of the fuel mix depends on the fuel economy, namely the price of each fuel type and miles/kilometers generated per unit amount of that fuel. Thus, the modeling system aims to analyze the role of trade policy distortions, the impact of biofuels blending mandates, and the implications of the U.S. and Brazil biofuel policies on land use changes, economic welfare and the total GHG emissions both at regional and aggregate level. A particular emphasis is given to the potential livestock intensification in Brazil, which would convert part of the pasture lands to cropland and expand the production of sugarcane and other major crops while simultaneously taking into account the effects on the domestic and foreign beef markets.

A fast growing literature on the economics of biofuels discusses the extent of land use changes and policy distortions including various analyses using partial equilibrium models focusing mostly on the U.S., EU and Brazil. Yet, there is little empirical research that investigates the potential for transition in the livestock production practices in Brazil and impacts of this on the growth of the biofuel sector and agricultural lands use. Nassar et al. (2009, 2011) and Elobeid et al. (2011) integrate the FAPRI-CARD model (Farm and Agricultural Policy Research Institute model) and BLUM (Brazilian Land Use Model) to simulate land use changes in the U.S. and Brazil. Both models are partial-equilibrium econometric frameworks including major agricultural and fuel commodities and cross effects between multiple commodity markets. BLUM additionally allows for new land expansion in Brazil through pasture intensification and deforestation starting with the total land available, including croplands, pastures and forests, and then estimating the increase in crop area and deforested area. The resulting difference between these two areas corresponds to the pasture area change. BLUM uses historical pasture stocking rates to allow cattle intensification as a means to release land for cropland expansion.

Nassar et al. (2009, 2011) assess the effect of a shock of additional 9 Blt of ethanol exported relative to the baseline scenario, which keeps the historical level of 2 Blt ethanol exports. Nassar et al. (2011) find that the sugarcane area would increase by 1M hectares (Ha) mostly coming from pasture areas, about 750 thousand Ha of which resulting from livestock intensification. Crop and livestock prices in Brazil would increase slightly while crops production other than sugarcane would remain unchanged. Elobeid et al. (2011) evaluate the impact of a 25 percent increase in global ethanol consumption relative to the FAPRI baseline scenario that reflects the current policies (consumption of 28 Blt, of which

50 percent is produced by Brazil). They find a 1.3M Ha increase in the sugarcane area in Brazil whereas pasture area would decrease by 550 thousands ha. However, when intensification occurs, pastures release an additional 100 thousand Ha of land.

This paper contributes to the related literature by developing a simultaneous framework that incorporates the interactions between food, feed and fuel sectors for analyzing the impacts of policy and technological changes on the biofuel economy and subsequent land use changes in Brazil, U.S. and Argentina. This study differs from the previous studies which addressed similar issues in several ways. First, it introduces an activity analysis approach, as opposed to econometric relationships, that simulates the beef-cattle sector and livestock intensification in Brazil to predict the land use changes in response to alternative biofuel policies both in Brazil and the U.S. The simulation aims to explore alternative intensification pathways for releasing new lands to expand the cropland and sugarcane plantation. The underlying hypothesis is that by transitioning to a more intensive system, average livestock productivity would increase, less grazing would take place, and hence less land would be required for livestock production. However, there would be trade-offs. Besides the increased operating costs, fixed costs of conversion, and cost of feed, some additional cropland has to be allocated to feed crops production, particularly corn and soybeans, to feed the animals under the new semi-intensive system. Secondly, this paper includes an explicit fuel transportation component in both the Brazil and the U.S. components of the model. This module is needed due to the relative importance of biofuels in the total transportation fuels consumption in both countries. The Brazil component also includes a component that reflects the transportation costs of gasoline and ethanol, which is important due to the size of the country and long distances when delivering fuels from production regions and refineries to consumption locations and export locations. A special consideration is given to the three pipelines projects that are recently launched which will transport ethanol from the Central-West and South-East Regions to four seaports (and intermediates stations) in the states of Rio de Janeiro, Sao Paulo and Parana. It is hypothesized that when these pipelines are built, the domestic transportation cost of ethanol domestically consumed or exports could decrease significantly (Scandiffio 2010), making sugarcane ethanol more competitive with gasoline. Finally, this research includes a fuel market mechanism that reflects the Brazilian fuel policies and pricing system accurately, which has not been addressed in the biofuel modeling literature.

To analyze the potential land use changes in Brazil and simulate the beef-cattle sector properly in the economic model it is necessary to describe briefly this sector and some assumptions in the model described in the next section. Brazil's pasturelands cover approximately 171M Ha, of which 91.5M Ha are planted pastures, 57M Ha are native pastures, 9.8M Ha are pastures planted but degraded, and the rest is fodder crops and area planted with forest species (IBGE 2006). Approximately 80 percent of this area is used by the beef-cattle herd, which ranges between 137 (IBGE 2006) and 165M heads (IBGE 2011a). This implies a stocking rate between 1 and 1.2 heads per Ha, a very low rate that could be increased by providing supplemental feed rations to the animals.

More than 40 percent of the cattle ranches raise their animals in a complete cycle from weaning to fattening; whereas the remaining ranches are devoted to one or two of the weaning, post-weaning, and fattening stages. Weaning ranches sell their calves to post-weaning and fattening ranches (IBGE 2006). For simplification purposes, the model restricts ranching activities to three categories: complete cycle, weaning and finishing (post-weaning and fattening together), which represent more than 81 percent of the beef-cattle production activities in Brazil (Martins et al. 2005). Each of these ranching systems is associated with a different cattle stocking rate, therefore a transition from one system to the other has implications on the pasture land use. Thus, simulating the amount of land that can be released through livestock intensification requires incorporating these three options as alternative production systems.

Brazil currently allocates 97 percent of the beef-cattle grazing pasture lands to an extensive livestock system (IBGE 2006), under which animals spend their life entirely in the pasture areas with minimal use of feed supplements (such as silage, corn grain, and soymeal). This lowers the annual beef cost and makes the industry economically very competitive in the world beef market. On the other hand, only about 3 percent of the beef cattle herd is subject to some kind of intensification by either feeding the cattle during the post-weaning and fattening stages and planting improved pasture varieties (semi-intensive systems) or confinement of the animals for 3 months during the fattening stage (feedlots or intensive systems) (AgraFNP 2008a; IBGE 2006; Martins et al. 2005). This paper explores only the semi-intensive system alternative.

2. The Model

We develop a multi-market, multi-product, spatial partial equilibrium model employing the well-known social-surplus maximization approach (Takayama and Judge 1971; McCarl and Spreen 1980; Martin 1981) to simulate the biofuel economy, trade policy, and the biofuel policies in Brazil and the U.S., including additionally the potential trade effect of some biofuel mandates in other countries. The social surplus (welfare) function is represented by the sum of producers' and consumers' surpluses, including the agricultural and fuel markets in the U.S., Brazil, Argentina[1], China, and the ROW. The objective function aggregates the consumer surpluses derived from consumption of agricultural commodities in all these countries, fuel consumption in China and the ROW and Vehicle Kilometers Traveled (*VKT*) in Brazil and the U.S. In the Brazil component, each Brazilian state is assigned a *VKT* demand function for the three vehicle types, namely conventional vehicles (*CV)*, flex-fuel vehicles:(*FFV)*, ethanol-dedicated vehicles (*EDV*). Each of the 27 states receives ethanol and gasoline from the nearest ethanol producing mesoregions, gasoline refineries or import port. Additionally, the model considers transportation of exported ethanol from the mesoregions in which they are produced to the nearest export port.

The supply and demand functions are all assumed to be linear and separable, except when the supply of crops is modeled explicitly by using Leontief (fixed input-output) production functions. These assumptions imply an additive quadratic utility function that represents the sum of producers' and consumers' surplus in the five global regions.

For the gasoline module, an upward sloping supply function is assumed for gasoline in the U.S., ROW, and China components while a perfectly elastic supply function is assumed in the case of Brazil reflecting the constant pricing policy for pure gasoline at the refinery level. Therefore, the model captures the effect of biofuel policies on gasoline prices through a feedback effect and thus on the demand for biofuels.

The total cost of producing agricultural commodities in each region is expressed as a linear function of the areas planted assuming fixed production costs for individual crops.

[1] The model does not include a fuel sector for Argentina.

The conventional fuel supply in each country and commodity export demands/import supplies are incorporated by using linear functions, where the total cost of trade includes the relevant trade margins (i.e. transportation and other costs). When modeling the ethanol trade to the U.S., trade distortions are taken into account including taxes and tariffs. Likewise, ethanol import through the CBI countries is included as a source of ethanol supply to the U.S. market. The objective function also includes the U.S. fuel blending subsidies (tax credits on blended fuels) and revenues from co-products, such as Distiller's Dried Grains with Solubles (DDGS) produced from corn during conversion to ethanol[2].

The agricultural supply side of the model is regionally disaggregated at mesoregion level in the Brazil component, at Crop reporting District (CRD) level in the U.S., and at state level in Argentina. In the three regionally disaggregated components, the model includes major annual crops/commodities produced using commonly practiced intra-year and inter-year crop rotation activities. The land allocated to all crops and pastures is constrained by the total agricultural land availability in each country and in each region. The comparative advantage between crop and livestock activities in each region is modeled explicitly based on the national and world prices, costs of production, processing costs, costs of transportation, and regional yields. Additionally, the U.S. component includes advanced biofuel production from corn stover, wheat straw, and from two perennial grasses, i.e. miscanthus and switchgrass, produced on regular crop lands, unused lands, and marginal lands. Crop production is modeled using Leontief production functions, where land is the primary input and crop yields are the output. Land is considered as the only

[2] The main co-product of sugarcane is the electricity co-generation. However, it is not considered in the model because only less than 10% of mills sell electricity surplus to the market, which represents less than 1% of total electricity supply in Brazil.

input whose availability is limited, while the availability of all other inputs (e.g. fertilizers, chemicals, seed, credit, labor, machinery services) is assumed to be unlimited at constant prices.

A difficulty that is often encountered when working with programming models is that optimum solutions generated by the model may involve extreme specialization in crop production where each region allocates all the land available in that region to a few (even a single) crops (corner solution), which is not realistic. This difficulty is addressed here by considering the 'crop mix' approach (McCarl, 1982; Önal & McCarl, 1991), where feasible solutions for total land allocation in a given region are restricted to be a convex combination of the historically observed crop patterns in that region.

In the Brazil beef-cattle component of the model, three pastureland categories are considered: 'planted in good conditions', 'planted degraded' and 'native' pastures. Each type of pasture can hold any of the three beef-cattle ranching activities: complete cycle, weaning and finishing. Semi-intensification systems are restricted to be implemented only on 'planted pastures in good conditions'. The model assumes that regional representative producers determine the optimal pastureland allocation to each activity, pasture type and livestock production system based on the beef-cattle costs in the region, including the cost of planting improved seed varieties and feeding the animals. A demand for feed is generated implicitly depending on the intensification level. The objective function considers therefore the trade-off between stocking rates and cost.

The optimal output levels based on the land allocations at regional level are aggregated to determine the national supply of agricultural commodities that can be consumed either in the domestic market as food, feed or biofuel feedstock, or exported, all of which are driven by downward-sloping linear demand functions. Besides primary commodity demands, the model includes four processed commodities: soymeal and soy oil from soybean, sugar from sugarcane and sugar beets, and beef from cattle grazing in pasture lands in Brazil.

Because of the size of the country and long distances between biofuel and fuel production regions and consumption/export locations, and ethanol transportation component is included in the Brazil component. Specifically, the model considers the distances and means of transportation with minimum costs (trucking vs. pipeline) from all mesoregions that are potential ethanol producers or have gasoline refineries to major domestic consumption areas and export ports. A special consideration is given to three pipelines projects that are recently launched and will transport ethanol from the Central-West and South-East Regions to four seaports and intermediates stations in the states of Rio de Janeiro, Sao Paulo and Parana. It is estimated that when these pipelines are built, the domestic transportation cost of ethanol for exports could decrease by fifty percent (Scandiffio 2010). It is expected that international ethanol trade will be most likely from Brazil to the U.S., China, and the ROW, however, the model allows ethanol trade in any direction.

The model allows sugarcane expansion only on the pasturelands within Agro-ecological Zoning for Sugarcane (ZAE-CANA) that are highly and moderately suitable for sugarcane production. The ZAE-CANA (Manzatto et al. 2009) aims to control the expansion process by defining the most suitable areas for sugarcane production considering physical, biological, socioeconomic and institutional-regulatory conditions (Zacamoto 2009). As a result, the legislation restricts the sugarcane production in more than eighty percent of the

Brazilian agricultural lands, including Amazonia, Pantanal and other sensible eco-systems.

3. Data and Assumptions

The model is calibrated and validated using 2007 as the base year. The data inputs include the base year domestic and global commodity prices and quantities demanded, historical crop mixes (areas planted to individual crops), crop yields, costs of production and processing, and cost of transportation. Crop mixes are restricted to the 2003-2009 data. Brazil is disaggregated into 137 spatial units where each unit is a mesoregion, the U.S. into 295 Crop Reporting Districts (CRD), and Argentina into 17 states.

The crops sector in the model includes sugarcane, alfalfa and eight major row annual crops: soybeans, corn, wheat, sugar beets, sorghum, oats, peanuts, cassava, dry-beans, cotton, rice and corn silage. Historical land use and crop yields are obtained from the Agricultural Municipality Survey (IBGE 2011b) for Brazil, U.S. and State Data Quick Stats 1.0. (USDA-NASS 2011) for the U.S., and Argentina Department of Agriculture (MINIAGRI 2011a) for Argentina. The data on pasture lands in Brazil are obtained from the official reports by the Agricultural Census (IBGE 2006). Finally, the marginal land availability in each CRD in the U.S. is as projected by Chen et al. (2011) for 2022.

For the ZAE-CANA, Manzatto et al. (2009) calculate that there are 19M Ha highly suitable and 41M Ha moderately suitable for sugarcane plantations, of which 11M Ha and 22M Ha respectively are currently used for livestock activities. We use the same data in our analysis.

The costs of row crops production include variable operating costs, fixed operating costs, capital and overhead costs, and hired labor costs. The data are gathered at state level (in some cases at municipality level) from PECEGE (2008), AgraFNP (2008a), CONAB (2011), EMBRAPA (2007a; 2007b), CEPEA (2008), Chen et al. (2011), and Oreja (2005).

In addition to crops, the model includes ethanol, beef and three agricultural processed goods: Soybean oil and soybean meal from soybean, sugar from sugarcane and sugar beets. Beef production in the model is the result of converting heads of adult live animals to animal units times the Brazilian slaughtering rate, expressed in terms of carcass weight. The related data are obtained from AgraFNP (2008a) and IBGE (2011a) . Based on these sources, we also calculate parameters for each type of ranching system, namely extensive and semi-intensive, and livestock production activity, namely weaning, finishing, and complete cycle, to convert the heads of adult live animals to pasture area required in each region. The weaning farms deliver calves and heifers to finishing farms assuming that beef production can come only from adult animals. The model includes cattle transportation cost per head per kilometer based on the information obtained from SIFRECA (2012).

As mentioned before, by transitioning to a more intensive system during the finishing stage, average livestock productivity would increase. This transition can be done through improved feed rations to adult animals up to an amount of 1.5 ton per AU per year, of which 70% corresponds to calories and 30% to proteins – calculated by the author based on the reports of Martins et al. (2005) and Lopes and Marques (2006). Currently, the amount of such improved feed rations is negligibly small. For simplification purposes, it is assummed that the only source of calories is corn grain and the source of proteins is soybean meal. Transition to a semi-intensive system is allowed only on planted pastures in good conditions. Ranches that adapt a semi-intensive system can reduce the life-cycle of animals to 3 years while under an extensive system animals spend 4 years on the farm. Since this is a one-year static model, the land use savings are incorporated by using a 25% reduction in the total pastureland per animal unit. When the model selects a semi-intensive system, there are stocking rate gains that release land for crop production activities. It is likely that degraded pastures would be the first to recover and convert to cropland. The cost of recovering one hectare of pasture degraded including labor, machinery and inputs is specified according to the information from AgraFNP (2008b).

In the fuel sector module, the two component models for the U.S. and Brazil consider a production function relationship between the transportation output (kilometers driven) and the amounts of different transportation fuels consumed. For the supply of gasoline in Brazil, we assume a fixed price of the pure gasoline at the refinery level, which is set at the current refinery price before taxes, market margins of the blenders, and transportation costs from the refinery to the blender locations as reported by ANP (2012). For China and the ROW, the model uses an upward sloping supply curve and a downward sloping demand curve for gasoline. The supply price elasticities are based on Lasco and Khanna (2010) and for the ROW from Goodwin, Dargay, and Hanly (2004). Since the U.S. and China are net gasoline importers, the baseline ROW quantity supplied is assumed as the amount imported by those two countries less the amount exported by Brazil.

Ethanol can be produced in the U.S. from corn and cellulosic biomass, and in Brazil from sugarcane. The amount of anhydrous ethanol produced per ton of corn and biomass and the amount of anhydrous and hydrous ethanol per ton of sugarcane and the respective conversion costs are specified at their reported levels under the current conversion technologies (Ellinger 2008; Chen et al. 2011; PECEGE 2008). In addition to the conversion costs, the model considers ethanol subsidies, co-product credits, marketing margins, delivering feedstocks costs to refinery and fuel taxes.

The demand functions for transportation (kilometers/miles driven) in Brazil and the U.S. are specified for each vehicle type (conventional, flex-fuel, and ethanol-dedicated) using a price elasticity, the price per kilometer driven and the total transportation distance generated in the base year. For Brazil, the demand function is distinguished from state to state. The price per *VKT* is obtained by dividing the total cost of the fuels consumed in the base year at the prevailing prices (including taxes) by the total distance traveled. For the U.S., the fuel prices and kilometers data by vehicle type are obtained from EIA (2010; 2008). For Brazil, the information is obtained from ANFAVEA (2011), DENATRAN (2010) and EPE (2011). The ROW demand for ethanol is equivalent to the Brazil exports excluding the exports to the U.S. Currently, China doesn’t import ethanol.

With respect to the agricultural commodity demands, the model uses 2007 quantities and 2006 and 2007 average prices (adjusted to constant 2007 prices) as the base year prices based on information from U.S. and State Data Quick Stats 1.0. (USDA-NASS 2011), Production, Supply and Distribution online (USDA-FAS 2011a), AgraFNP (AgraFNP 2008a; AgraFNP 2008b), Monthly Market Prices in Argentinean Ports by the Department of Agriculture (MINIAGRI 2011b).

The price elasticities used in the demand functions are obtained from various sources, including ERS (2011), Marsh (2007), Adams et al. (2005), Carley and Fletcher (1989), Gao, Wailes, and Cramer (1995), Piggott and Wohlgenant (2002), FAPRI (2011), Fortenbery and Park (2008), Bredahl, Meyers, and Collins (1979). The base year demand quantities by the ROW correspond to the exports from Argentina, Brazil, China and the U.S.

The international trade data was mainly gathered from AgraFNP (2008b; 2008a) and FAS (USDA-FAS 2011a; USDA-FAS 2011b).

Domestic costs of transportation for the crop/commodities in Brazil are as those reported by SIFRECA (2012). Domestic costs of transportation in the U.S. result from the difference between farm prices and FOB prices, whereas international costs of transportation are derived by using the differences between FOB prices at the main ports in each country. The main ports in ROW are Rotterdam and Hamburg. The FOB prices sources are: Market Prices in Argentinean Ports by the Department of Agriculture (MINIAGRI 2011b), Eurostat by the European Commission (European-Commision 2011), prices reported by AgraFNP (2008b; 2008a), the International Commodity Prices data base by FAO (FAO 2011), the Global Agricultural Trade System (GATS) by Foreign Agricultural Service of USDA (USDA-FAS 2011b), and COMTRADE database of United Nations (United Nations 2011).

For the ethanol sector, the domestic costs of transportation in the U.S. from refineries to blenders are obtained from Chen et al. (2011). For Brazil, the transportation costs are based on the road distance among the main cities or towns in each mesoregion and the cost per liter per kilometer based on the estimates in SIFRECA (2012). For the cost of ethanol transportation through pipelines, the routes and distances are based on the reports by EPE (2008), Scandiffio (2010), and CentroSul (2009). The model allows delivering and collecting ethanol in specified intermediate stations. International costs of transportation of ethanol are based on Crago et al. (2010), but for the Brazilian ethanol exported to the U.S. through the CBI countries is slightly higher due to handling and dehydration costs.

The GHG emissions in Brazil due to land use changes are of particular concern. The related data are calculated for livestock production, all crops and fuels based on the above-ground CO_2 equivalent (CO_2e) emissions. The CO_2e emissions are estimated by aggregating the major GHGs emitted, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), using their 100-year global warming potential factors. Most of emissions factors are as those reported in the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation 1 (GREET 1) by Argonne National Laboratory (2011).

GHG emissions for ethanol in the U.S. are obtained from Chen et al. (2011) including the emissions from energy used to transport the feedstock to a biorefinery, to convert the feedstock to fuel, and the transport of the biofuel for final consumption also accounting for the co-product credits. For GHG emissions from sugarcane ethanol in Brazil, we adapt the estimates by Soares, Alves, Urquiaga, & Boddey (2009) including the emissions from planting, maintaining, harvesting, and feedstock transportation including the emissions in international transportation of ethanol as reported by Crago et al. (2010). It is important to note that the GHG emissions do not include emissions related to indirect land use changes. For gasoline emissions in Brazil, we distinguish three separate components: emissions from well to refinery, from pump to wheel (Schmitt, Szklo, and Schaeffer 2011), and from refinery to the pump (CEFIC&ECTA 2011).

For the beef-cattle sector in Brazil, we use the data reported by Cardoso (2012), which are closely related to the beef-cattle systems adapted in the model. GHG emissions per animal unit raised depends on whether an extensive or semi-intensive system is used which vary between degrade pastures, native pastures and planted pastures. The difference from one system to another is related to the nutritional facts and health care management such as regularity of vaccinations and veterinary visits.

For the projections, supply and demand curves and yields are shifted out over time according to both a simple moving average of their historical values and projections of ERS outlook reports (USDA-ERS 2011b).

The VKTs in the U.S. are set at the levels projected by EIA (2010). In Brazil VKTs vary by state and they are assumed to increase linearly according to the historical trend of the vehicle fleet reported by ANFAVEA (2011) and DENATRAN (2010).

The ROW demand for ethanol is taken from the values in of OECD-FAO (2011), which considers among others the EU and Canada's mandates. As argued by Araújo and Lu (2010), China could import some biofuels from Brazil, which is assumed as the demand for ethanol by this country in the 2022 simulations.

The model assumes that that the current unit cost of conversion of feedstock to biofuel (C_{cum}) declines across time depending on the ethanol cumulative production (CUM) according to the equation $C_{cum} = C_0 \cdot CUM^b$, where C_0 is the cost of the first unit of production and b is the experience index. To find the most accurate b it has to be considered a progress ratio (PR) representing the rate at which average costs decline with each doubling of cumulative production (i.e. $PR = 2^b$). The model assumes PR for the three feedstocks following the estimates in van den Wall Bake et al. (2009), Chen and Khanna (2012) and Chen et al. (2011).

The entire data set, including the key supply and demand parameters, production costs and yields, and transportation costs between regions can be available from the authors upon request.

4. Policy Scenarios and Results

We analyze two trade and biofuel policy scenarios along with a livestock intensification scenario in Brazil and use the model to determine their implications. Particular emphasis is placed on the U.S.-Brazil bilateral trade, GHG emissions and welfare of producers and consumers. These scenarios are described below together with the results obtained from the model in each case. Prior to the policy scenario analyses the model needs to be validated to ensure that it has reasonably satisfactory simulation performance. This is done first and the validation results are summarized in section 4.1. The subsequent sections present the empirical results obtained from the model under different scenarios.

4.1. Model Validation

The baseline scenario reflects the 2007 policy conditions for the purposes of model validation. Since the actual ethanol consumption in the U.S. in 2007 exceeded the RFS mandate for that year, the mandate constraints are relaxed in the model. The ethanol import tariffs and blender subsidies implemented in 2007 remain in place.

Table 4.1 summarizes the market equilibrium solution in the modeled baseline for the U.S. The results for land use and crop prices are usually within acceptable margins of error. The ethanol imported from Brazil (1.88 Blt) is almost equal to 7% of the U.S. consumption, which is the cap for the CBI countries that process hydrous ethanol imported from Brazil and re-exported to the U.S.

[Insert Table 4.1 here]

Tables 4.2 reports the validation results for Brazil. The land use and crop prices determined by the model are again within acceptable ranges. The pasture areas (table 4.2

and figure 4.2) and beef prices show very good fit, thus highlighting the good performance of the model. The fuel prices and consumption values are also within a small range around the values observed.

[Insert Table 4.2 here]

Figure 4.1 illustrates the land use results for sugarcane in Brazil. The map shows a very small deviation in the regional distribution of cropland allocation and highlights the concentration of sugarcane in the *traditional sugarcane production region*.

[Insert Figure 4.1 here]

Finally, table 4.3 presents the model results for Argentina. Land allocation fits well for the three crops as well as crop prices.

[Insert Table 4.3 here]

These small deviations notwithstanding, the model appears to reasonably replicate the base-year market equilibrium conditions in all three countries. Thus, we proceed with the scenario analysis.

4.2. Effect of Biofuel Policies in 2022

The model simulates two trade and biofuel policy scenarios stated for year 2022 (the last year of the policy period for which the RFS targets have been stated) to analyze their implications on land allocation, international trade, food and fuel prices, GHG emissions, and welfare of producers and consumers.

For Brazil, the model considers the maximum blending mandate, namely the proportion of anhydrous ethanol blended into gasoline must be 25%, the tax rates applied to gasoline and ethanol both at federal and state levels, and the regulated refinery price of gasoline. In the U.S. component, the biofuel blending mandates, tax credit for gasoline blenders, the cellulosic ethanol subsidy, and the import barriers, namely the tariff rate per unit and ad valorem tax, are maintained at their base year levels assuming that they will continue as dictated by the RFS. Increasing imports by the ROW and China are due to the mandates imposed in Europe and China.

The model projections for year 2022 are presented in such a way that in each scenario an extra policy is added. In the policy analysis, the case without any biofuel policy in the US, which is referred to a 'Business-As-Usual' (BAU) scenario from here on, is considered as the 2022 baseline. The first policy scenario considers the U.S. biofuel policies (i.e. RFS mandates, import barriers and the subsidies) and imports from the ROW and China, the second scenario removes the U.S. incentives and includes only mandates and imports from the ROW and China. Tables 4.2-4.8 summarize the model simulation results for the agricultural and fuel markets in year 2022.

[Insert Tables 4.4-4.8 here]

4.2.1. The Benchmark - BAU Scenario

The first column in tables 4.4-4.8 reports the results for this scenario when the beef-cattle sector in Brazil is allowed to expand. For Brazil, the total cropland would increase by 6.5Million Ha relative to the 2007 cropland use, which would come mainly from converting pasture areas to cropland (Table 4.4). As a consequence, beef production would decrease by 3.5% and intensification rate (the number of cattle finished in a semi-intensive system relative to the total herd size) would change from 1.62% in the validation run to 11.45%. Beef supply reduction is followed by a significant beef price escalation. As expected, corn and soybean areas would expand significantly to supply feed supplements to the livestock sector and to export to the international markets. Similarly, sugarcane production would increase by 82% to meet the bigger domestic and export demand for both ethanol and sugar. As a result of the crop/commodity production changes, prices of corn, soybean, and sugar would increase by 10%, 33%, and 5% (Table 4.4), respectively. In the fuel sector, ethanol production would double with respect to the 2007 level, of which 95% would be consumed domestically. The gasohol price would remain virtually unchanged, while the pure hydrous ethanol (E100) price would decrease slightly. The price of unit distance traveled for flex vehicles (FFV) and conventional vehicles (CV) would decrease some and total VKT would more than double (Table 4.7). The main reason for the discrepancy between the changes in fuel and VKT prices is due the fixed price of gasoline, which moves along of perfectly elastic supply curve.

For the U.S. under the BAU scenario, soybean and wheat acreage would increase by 5% and 3% respectively while corn area decreases by 2% relative to the 2007 baseline (Table 4.5). The soybean production increase is due to the high level of exports, particularly due to the demand growth of China. Despite the area expansion and production increases the prices of, corn, soybean and wheat increase considerably (Table 4.5), this is due to a larger shift in demand compared to the production increase. In the fuel sector, corn ethanol would increase from its 2007 level of 24.7 to 31.5 Blt, cellulosic ethanol would not be produced despite the assumption of low cost and high productivity of cellulosic biomass, and there would be no ethanol import from Brazil (Table 4.8). Consequently, domestic consumption becomes slightly higher than that observed in 2007. As a result, the U.S. ethanol demand would be higher than the minimum oxygenator blending requirement (which is assumed 3.5% of the total fuel consumption). Likewise, the price of VKT for both conventional and flex vehicle types would decrease by more than 13%, gasohol and E85 prices would increase by 5% in 2022 compared to the 2007 levels (Table 4.8).

For Argentina, the total cropland would increase by 2.6% with respect to the cropland in 2007, mainly due to the increase in corn acreage. Corn, soybean and wheat exports would increase to some extent while soybean products would remain at their base year levels. Thus, similar to the U.S. case, corn, soybean and wheat prices would increase significantly (Table 4.6). The low price elasticities explain why the price changes are so high although the decreases in the consumed quantities in domestic markets are relatively small.

4.2.2. Scenario-1: Mandates Plus U.S. Import Barriers and Biofuel Subsidies

The second scenario includes the U.S. tariffs on imported biofuel and blender tax credits (subsidies) on conventional (corn) ethanol and cellulosic ethanol, the RFS mandates and the increasing import due to the mandates in the ROW and China. Although recently the subsidy incentives and tariffs in the U.S. have been removed, the present analysis aims at shedding light on the implications of these policy changes and provides insight to policy makers. For practical purposes, this policy scenario is called hereafter "*all-inclusive policy*". The empirical results are presented in the second column in tables 4.4-4.8. A brief discussion of the major findings is below.

The total cropland use in Brazil would increase by 8.4%, with a 19% rebound of corn area with respect to the BAU scenario. Sugarcane area would increase by 13% while soybean area would remain at the same level of the BAU case. The pasture area would be reduced to some extent and beef production would go down slightly, although significant (12%) intensification would take place (Table 4.4). Corn production would increase significantly (from 62M ton to 75M ton) as a result of filling the international market demand which was previously supplied by the U.S. The price effect on corn and beef would be substantial, while sugar and soybean prices would increase somewhat compared to the BAU levels. In the fuel sector, sugarcane ethanol production would be about 57 Blt, 24% more than the BAU level, most of which is consumed domestically (72%) and the rest is exported to U.S. (9.4 Blt), China and ROW (2.8 Blt) and the ROW (3.4 Blt). The gasohol price would increase marginally while E100 price would drop slightly. VKT prices by CV and EDV would remain about same level as BAU, whereas VKT by FFV would up by 1.3%. Total VKT would remain about the same level as BAU (Table 4.7). Thus the impacts of the trade liberalization on Brazilian transportation fuel sector would be negligibly small.

In the U.S., the total ethanol use would just meet the total mandated amount. Cellulosic ethanol would be the main source, 74.8 Blt, considerably above the "advanced" ethanol mandate and representing 57% of the U.S ethanol market. However, corn ethanol would also increase to 53.2 Blt (69%) relative to the BAU case. Sugarcane ethanol imports would meet only 7% of the total domestic consumption, which is the maximum quota for the CBI countries, and would fill the rest of the advanced biofuel mandate and a very small portion of the conventional ethanol mandate (Table 4.8). The dominating share of cellulosic ethanol is mainly due to the assumption of progress ratio (PR) of 0.8 based on Chen et al. (2011). This assumption represents an average efficiency increase in newly introduced industries, which is assumed to hold for cellulosic ethanol processing also. Clearly if this assumption is too optimistic the model results would be quite different. In the "*all-inclusive policy*" scenario, the U.S. would export 5 Blt of corn ethanol to the ROW and China, which is consistent with the current trends in international ethanol trade. There would be a significant reduction in the price of VKT, gasohol, and E85 while total VKT would increase by 1.4% with respect to the BAU scenario (Table 4.8). In the agricultural sector, corn acreage would increase by 1.4% while soybean and wheat would drop further by more than 5% each. Miscanthus area in the U.S. would be 9.3M Ha, while switchgrass area would be just 0.7M Ha. Ethanol production would utilize significantly more corn and therefore reduce the exports of corn considerably. Hence, there would be a large increase in the price of corn compared to the BAU scenario (Table 4.5). These results indicate the important role of protectionist trade policies in the U.S., which were needed during the infancy of the U.S. corn ethanol industry.

To illustrate the sensitivity contained on the parameter PR under "*all-inclusive policy*" scenario, we compare two progress ratios, namely 0.95 and 0.99, which means that costs of processing cellulosic ethanol would decline slower. Thus, production of cellulosic ethanol would only meet the U.S. mandate, i.e. production would decrease from 74.8 to 60.5 Blt, imported sugarcane ethanol would fill the rest of the 'advanced mandate', corn ethanol would meet the rest of the total RFS and the U.S. would not export ethanol. (we do not report these results tabulated but they are available from the authors upon request).

In Argentina, corn production would increase significantly due to the increasing exports, which is a consequence of the U.S. corn exports reduction (Table 4.6). These changes would have a direct and significant impact on the domestic prices of corn (26%).

4.2.3. Scenario-2: Mandates-Only

The third column in tables 4.4-4.8 presents the results of considering only the RFS mandates and increasing imports due to the mandates in the ROW and China. The following analysis is relative to the "*all-inclusive policy*" scenario.

The total sugarcane area and production in Brazil would expand further by about 20%, while the corn area would decline a little and pastureland would remain almost the same. The main reason for the expanding sugarcane production is the demand for sugarcane ethanol in the U.S., which becomes a more economical fuel compared to cellulosic ethanol. This explains the importance of implementing the import tariff and tax policies in the U.S. when the RFS mandates are imposed and the domestic ethanol industry is exposed to foreign competition. To create the additional land for sugarcane production the intensification rate would increase by 16% with respect to the "*all-inclusive policy*" scenario (Table 4.4). In the fuel sector, sugarcane ethanol production would go up from 56 Blt under the "*all-inclusive policy*" to 75.5 Blt, of which 25.3 Blt are exported to the U.S. market including 9.2 Blt through the CBI countries (Table 4.7). Due to the higher level of ethanol exports, E100 price in Brazil would increase by 2%, while gasohol price would remain same; hence, the VKT price paid by CV's would not change, while for FFV and EDV the cost of unit transportation would go up by 1.5% and 2.3% respectively. The different rates of price changes is because of the fuel composition and differential price changes for the fuel types consumed by each vehicle category. The total VKT by all vehicle categories would remain virtually unchanged (Table 4.7).

On the U.S. side, although corn and cellulosic ethanol production would decrease (by 12% and 19%, respectively) relative to the "*all-inclusive policies*" scenario most of the domestic ethanol demand would still be supplied domestically (81%). Again cellulosic ethanol would be the main source of biofuel with an annual production of 60.5 Blt, which is equivalent to the cellulosic mandate. Imported sugarcane ethanol (25.2 Blt, three times higher than the imports under the all-inclusive scenario) would fill the remaining 'advanced biofuel' mandate of the RFS and also substitute a portion of the conventional ethanol. There would not be significant changes in the prices of VKT and fuel (Table 4.8). In the agricultural sector, traditional crops would change insignificantly, while aggregated energy crops area would decline significantly. Ethanol production would utilize less corn, so that exports would increase by 11% (Table 4.5). As a result of the corn supply changes in the U.S., the price of corn would go down considerably.

4.2.4. Spatial Distribution of land use in Brazil under alternative biofuel policies

This section presents the land allocation in Brazil under the BAU and the land use change under the two policies scenarios described above. Figure 4.2 shows the regional land allocation for sugarcane in each of the three cases. The higher the sugarcane ethanol production, the more land is dedicated to sugarcane in San Jose do Rio Preto mesoregion in northwestern Sao Paulo, Triangulo Mineiro/Alto Paranaiba, northwestern and south/southeastern mesoregions in Minas Gerais, central and southern regions in Goias, and southeastern region in Mato Grosso do Sul. Likewise, some regions in the states of Mato Grosso, Maranhao and Bahia show potential as a second expansion region. The sugarcane intensive regions are determined based on the combined effect of the truck transportation costs favoring the regions closest to the export ports, and the regions with relatively higher sugarcane yields. Specifically, under the BAU, sugarcane production would increase significantly in *the region of expansion* (western Sao Paulo, northern Parana, southern Mato Grosso do Sul, southern Goias, and southern Minas Gerais) as it actually happened in year 2010. When the entire set of U.S. biofuel policies is included in the analysis, sugarcane area would increase only slightly in the *traditional region*, while other regions would decrease their production. Under the "*mandates-only*" scenario, most of the sugarcane expansion relative to the BAU would occur in Southwestern Mato Grosso do Sul and Southern Goias. Some mesoregions in the *Northeast* region would also start planting sugarcane. This is an expected result because of the increasing amount of exports mainly due to removed incentives to domestic ethanol producers in the U.S.

[Insert Figure 4.2 here]

Figure 4.3 shows the results for corn area under the three scenarios. Under the "*all-inclusive policy*" scenario, Mato Grosso do Sul and Parana would increase their corn production significantly. When only the mandates are considered, northern Mato Grosso and western Mato Grosso do Sul would decrease their production relative to BAU case and most of the regions would have a slight increase except for eastern Mato Grosso do Sul which would expand it significantly.

[Insert Figure 4.3 here]

Soybean acreage results are displayed in figure 4.4 under various scenarios. The regional distribution confirms the relevance of the "Deforestation Arch" for the expansion of soybean acreage and explains how sugarcane would have to compete for cropland in the *region of expansion*. The "Deforestation Arch" is the main region where the agricultural frontier advances toward the rainforest and also where the highest rates of deforestation in the Amazon are. It includes an area of 50M Ha from eastern and southern Pará westward, passing through Mato Grosso, Rondonia and Acre. Under the "*all-inclusive policy*" scenario, soybean expansion shows how the sector would expand over the "Deforestation Arch"; under the "*mandates-only*" scenario, however, southern Brazil and the *region of expansion* would decrease their soybean production and expansion would be more intensive over the "Deforestation Arch".

[Insert Figure 4.4 here]

Figure 4.5 reports the pasture land use in Brazil. The beef-cattle sector would exert pressure not only on the "Deforestation Arch" but also in the Pantanal region, which is the largest Brazilian wetland known with its high environmental value and ecosystem services. Both policy scenarios would lead to a pasture land reduction in northern Mato Grosso, Western Pará, southeastern Mato Grosso do Sul and southern Goias due to the conversion of pasture lands to sugarcane plantation.

[Insert Figure 4.5 here]

Figure 4.6 shows the spatial distribution of the livestock intensification (green dots) and the new cropland distribution. Under the BAU scenario, the *region of expansion* and the "Deforestation Arch" would have the highest new cropland, followed by some new areas in Parana state. The beef-cattle intensification process would be highly concentrated in the states of Tocantis, Maranhao, Goias and Rio de Janeiro. Under the "*all-inclusive policy*" scenario all regions would convert some of their pasture lands to crop production. Intensification would expand in the Northeastern region also including the states of Piaui, Bahia and Maranhao. When sugarcane production increases as a result of relaxed U.S. biofuel trade policies, more new cropland would come from the "Deforestation Arch", southeastern Mato Grosso do Sul and southern Goias.

[Insert Figure 4.6 here]

Under the "*mandates-only*" and "*all-inclusive policy*" scenarios, the additional ethanol production (11 and 30 Blt, respectively) would require additional 1.2 and 3.4 M Ha of new sugarcane area, which would come from other crops and particularly from pasture uses. The average rate of expansion would be 115 Ha per million liters of ethanol. Nassar et al.

(2009) find a very similar rate, namely 111 Ha/million liters, while Elobeid et al. (2011) find a much lower rate, 53.1 Ha/million liters, due to a smaller shock to the ethanol production.

4.2.5. Environmental and Welfare Effects

Overall, when the model includes all of the U.S. biofuel policies, the total GHG emissions (in CO_2e) by the U.S., Brazil, and Argentina would reduce by 0.23 Billion metric tons (which corresponds to an 11% reduction) relative to the BAU. The reduction is actually achieved by the U.S., by almost 0.25Billion metric tons, while Brazil and Argentina increase their total emissions. Under the "*mandates-only"* scenario, there would be 2% less reduction in the total GHG emissions relative to the previous scenario due to Brazilian vehicle fleet would be using more gasohol than E100 and the U.S. would be producing significantly less cellulosic ethanol, which would be the main emissions saver (see table 4.9).

[Insert Table 4.9. here]

The welfare effects of the policy scenarios considered here are also reported in table 4.9. Under the "*all-inclusive policy*" scenario, Brazilian gasoline and ethanol producers would have a welfare (income) gain by 5.8% relative to the BAU benchmark while fuel consumers would be marginally worse off. The main source of the consumer welfare loss is the reduced driving demand as a result of increased fuel prices (see table 4.7). On the U.S. side, fuel producers would be significantly better off with respect to the BAU scenario due to the incentives received. Similarly, fuel consumers would be slightly better off due to the increase in VKT (see table 4.8). Similar results would hold for fuel consumers and producers in both countries under the "*mandates-only*" scenario, except that the U.S. fuel producers would reduce their incomes due to the lack of incentives to produce ethanol at a similar level observed in the "*all-inclusive policy*" scenario.

On the agriculture side, producers in both countries would obtain large gains with respect to the BAU case under the "*all-inclusive policy*" scenario. U.S agricultural producers would gain the highest benefits particularly due to the high price of corn. The share of cellulosic biomass producers in the increased producers' net income would be substantial, about $17 billion (10% of the total agricultural producers' surplus). On the other hand, both American and Brazilians food consumers would face substantial losses mainly due to the high price of corn and other crop products. Conversely, when the "*mandates-only*" scenario is considered the gains accruing to U.S. agricultural producers would decline by 9%, while consumers would be better off relative to the "*all-inclusive policy*" scenario.

Finally, the Brazilian government would have increased tax revenues under both policy scenarios. The U.S. government would make positive gains under the "*mandates-only"* scenario, but when the subsidies and tariffs are in place the situation is reversed since the financial incentives provided to fuel blenders exceed the returns from import tariffs, thus causing a net revenue loss for the government.

In summary, as the last panel of table 4.9 shows, both the U.S. and Brazilian total social welfare would increase at varying rates under the two policy scenarios, but the highest gains would occur to Brazil's social welfare under the current biofuel policy (i.e. the "*mandates-only*" case).

The reported results are consistent with intuition. Implementing the U.S. biofuel policies fully reduces the amount of U.S. corn in the world market because a significant portion of the corn supply is diverted to domestic ethanol production in order to meet the

RFS total ethanol mandate and other provisions. This result supports the theoretical argument made by de Gorter and Just (2008), where it was demonstrated that the U.S. ethanol producers would benefit most from a mandate combined with a tariff and subsidies, while keeping the mandate but removing the accompanying policies provides enormous benefits to fuel and agricultural producers in the ethanol exporting country. Furthermore, we also observe that by comparing the model baseline with the 2022 scenarios, an increased ethanol supply and increased sugarcane production could be effectively facilitated by intensifying the livestock production systems in Brazil. We observe that transition towards a semi-intensive livestock system would release the land required to increase both corn and sugarcane production, while diminishing the negative effect on Brazil's share in the world beef market (Table 4.4).

4.3. Ethanol transportation alternative in Brazil

Because of the size of the country and long distances between biofuel production regions and consumption/export locations, the sugarcane industry and PETROBRAS are currently building an ethanol transport pipeline and are planning to develop two more in the future to transport the ethanol that will be produced in the Central-West and South-East Regions to four seaports (and intermediate stations) in the states of Rio de Janeiro, Sao Paulo and Parana. It is estimated that when these pipelines are built, the domestic transportation cost of ethanol for exports could decrease by fifty percent (Scandiffio 2010).

The model developed here considers the roadway distances and means of transportation with minimum costs (trucking vs. pipeline) to transport the ethanol from all mesoregions that are potential ethanol producers to major domestic consumption areas and export ports. It is most likely that the 'mandates-only' scenario will be the near future policy environment in the US. This will open up the US market to foreign biofuel competition, particularly Brazilian sugarcane ethanol. Imported Brazilian ethanol may meet not only the demand for advanced ethanol but also the total ethanol mandate if the cellulosic ethanol production falls short of the projected increases due to a cost disadvantage. In that case the gap could be filled by the sugarcane ethanol imported from Brazil. Another source of export expansion for Brazilian ethanol is the Europe and Asia markets. This would encourage Brazil to expand the sugarcane and ethanol production beyond the current (traditional) production regions. The large transportation distances and the inefficiency of the current infrastructure would be cost disadvantages and may hamper the development of the industry further in those regions. The recently launched ethanol pipeline projects may address this issue and offer economic benefits. In this section, I analyze the impacts of the two trade and biofuel policy scenarios described earlier assuming that these ethanol pipelines are fully operational. Tables 4.10-4.12 report the results. A brief discussion of the results is below.

In Brazil under the "*mandates-only*" scenario the ethanol production and international trade would change to some extent. The pipelines would increase the production by 2 Blt with respect to the scenario without the pipelines and Brazil's ethanol exports may go up also by the same amount. Although positive, this result is not a significant improvement and may not necessarily justify the development of these pipelines. This result makes sense because without an increase in the ethanol demand beyond the current level there is no compelling reason for expanding the ethanol production in inland regions.

The situation would change dramatically under the "*all-inclusive policy*" scenario. The sugarcane ethanol production would be 74.7 Blt, of which 34.5 Blt would be exported to the

U.S. The amount of ethanol production is 20 Blt more (32%) than the corresponding value in the scenario without pipelines (see tables 4.7 and 4.10). In turn, because of the increased and less expensive supply of ethanol from Brazil the U.S. biofuels sector would decrease its corn and cellulosic ethanol production by 10 and 9 Blt, respectively (see tables 4.8 and 4.11). This demonstrates the competitiveness gained by sugarcane ethanol due to the pipelines vis a vis cellulosic and corn ethanol. It is also interesting to note that the U.S. would increase its ethanol exports to ROW and China from 5 Blt to 11.3 Blt under the "*all-inclusive policy*" scenario because the U.S imports from Brazil would meet the "advanced" biofuel demand, but the existing corn ethanol production capacity has the potential to produce more corn ethanol and export it to those countries.

[Insert Table 4.10-4.12 here]

There will not be significant changes in the land use under the "*mandates-only*" scenario when the pipelines are included. Under the "*all-inclusive policy*" scenario, the sugarcane area would expand 2M Ha further (20%) relative to the scenario without pipelines (tables 4.4 and 4.12); half of this comes from the pasture area, 1M Ha. Figure 4.7 shows the regional land allocation to sugarcane under the two scenarios with and without the pipelines. Southwest of Mato Grosso do Sul and Southern Goias are the regions most influenced by pipelines because these regions have high sugarcane yields and close to the pipelines, which offer a comparative advantage in both sugarcane and ethanol production. Consequently, the land allocated to corn and soybean production would be slightly reduced and production of these crops would take place in other less productive regions. As a result, corn exports would drop significantly relative to the no-pipeline scenario.

[Insert Figures 4.7 here]

Table 4.13 reports the welfare effects of the three pipeline projects. When the subsidies and tariffs are imposed, social welfare in Brazil would be larger when the pipelines are in place. However, the situation would be different for the U.S. side. Although consumers would be better off, producers' gains would go down compared to the "no-pipelines" scenario because of two reasons. First, the price of corn would not be as high as in the no-pipeline case. Second there will be a significant decline in the domestic ethanol production because of the cost advantage for Brazilian sugarcane ethanol. Particularly cellulosic ethanol production would go down which also reduces the biomass producers' net incomes. As a whole, the aggregate social welfare in the U.S. would be reduced compared to the no-pipeline case (see tables 4.9 and 4.13). On the other hand, the impact of pipeline-induced cost advantage on ethanol production would be small under the "*mandates-only*" scenario. This is because the room for further exports from Brazil to the U.S. is limited due to the cellulosic biofuel mandate imposed by the RFS. Even though sugarcane ethanol is increasingly inexpensive compared to cellulosic ethanol, there would not be further exports since sugarcane ethanol does not meet the cellulosic biofuel mandate and the advance biofuel mandates were met even in the absence of the pipelines. This finding suggests that the development of these pipelines is not justified based on the projections of expansion in the U.S. market, which will be limited (unless RFS requirements are modified and the share of advanced biofuels mandate in the total mandated amount is increased at the expense of cellulosic biofuels). However, the pipelines can still be justifiable if expansion in ethanol demand occurs in other markets, such as Europe and China.

[Insert Table 4.13 here]

Conclusions

Projecting the market conditions in 2022, I find that a free ethanol trade regime would reduce the domestic ethanol production in the U.S. When implementing the mandates and resuming the recently removed U.S. biofuel incentives, aggregate welfare in U.S. would remain virtually unchanged, while in Brazil the social welfare would be increased. The total U.S. ethanol consumption would just meet the total mandated amount, cellulosic ethanol would be the main source and corn ethanol production would be also high. Hence the U.S. would export some ethanol to ROW and China confirming the current ethanol international trade trend. When only applying world mandates, Brazil would supply its domestic ethanol demand and would export about half of its production to U.S., China and the ROW, while all of the U.S. production, including both corn and cellulosic ethanol, would be consumed in the domestic market. Here, we find further evidence that the multi-market effects of biofuel policy are quite far-reaching.

With regards to the land use, the model results show that under the current policies intensifying the current livestock systems in Brazil would release a significant amount of land for corn and soybean production across the country and sugarcane planted area would expand in the denominated "*region of expansion*". The competition for land between these crops depends on their own demands and also on the increased demand for supplemental feed demand resulting from livestock intensification. Hence, we find that the livestock semi-intensification through feeding the beef cattle in the finishing stage will dominate the land conversion process in Brazil due to high world ethanol demand rather than deforestation and savannah conversion, which ultimately implies aggregated reduced GHG emissions.

In addition, we find that ethanol transportation infrastructure development in Brazil (e.g. pipelines) would further increase the Brazilian total welfare.

The analysis provides insight into the multi-market dimensions of the biofuel economy, in particular, the land use changes due to the policy climate in the U.S. and the resource base in Brazil. Through this framework, I am able to identify the key linkages between land use, GHG, agricultural commodities, and transportation fuels. Finally, it is evident that the U.S. and Brazil biofuel policies do exert influence over global agricultural markets.

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Figures

Figure 4.1. Area sugarcane planted in Brazil 2007 (1000 Ha)

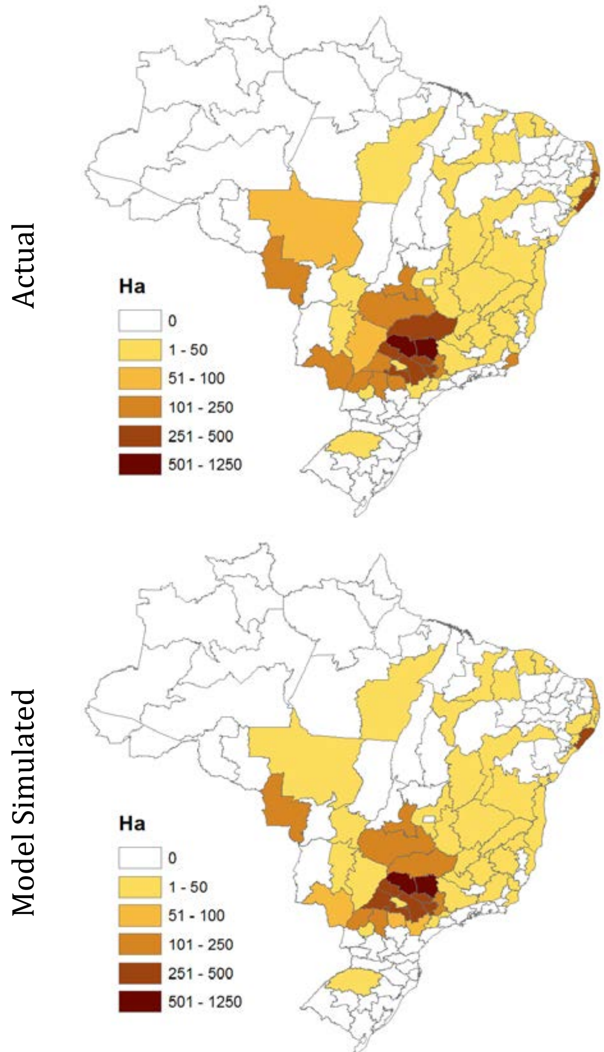


Figure 4.2. Area sugarcane simulated in Brazil 2022 (1000 Ha)

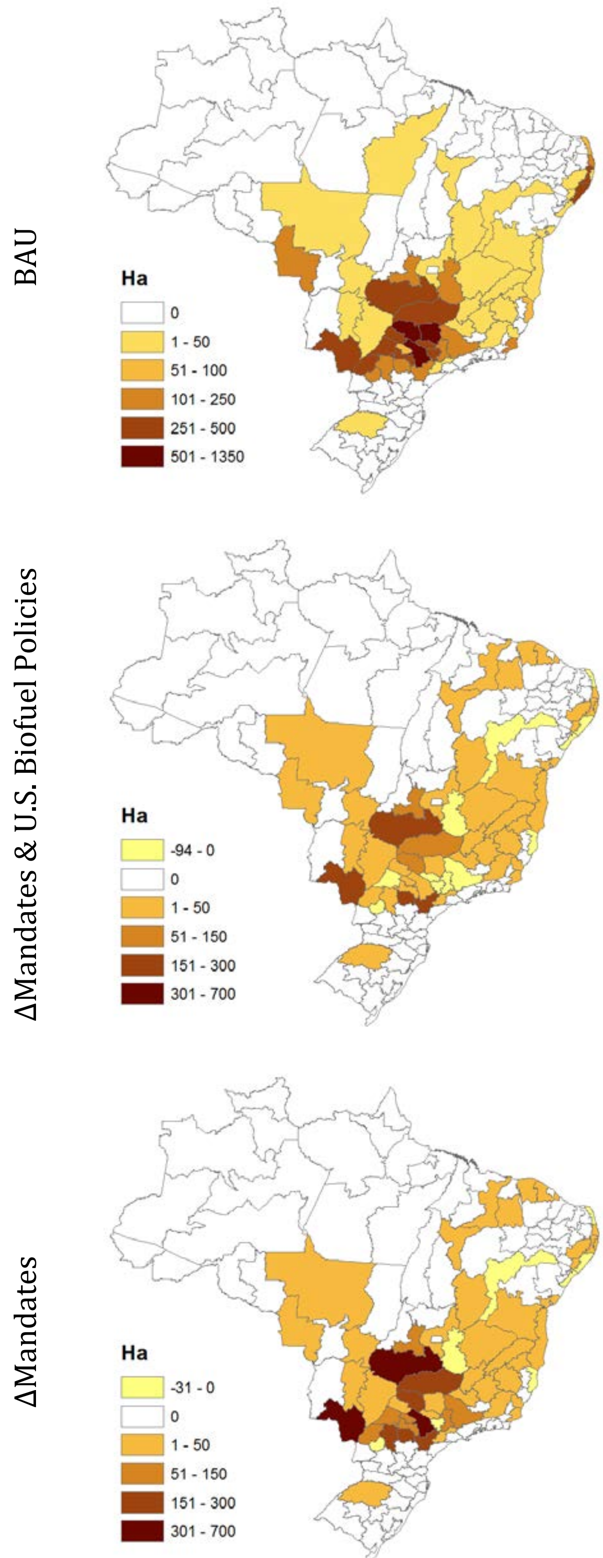


Figure 4.3. Area Corn simulated in Brazil 2022 (1000 Ha)

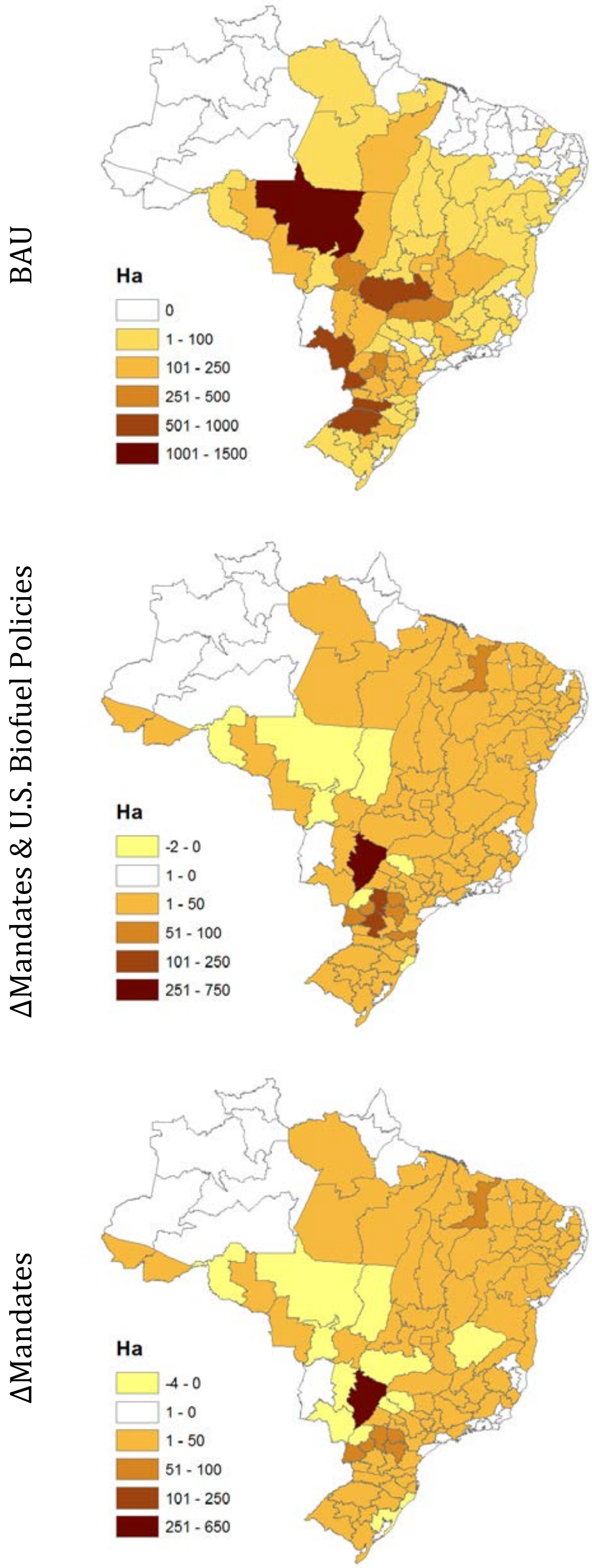


Figure 4.4. Area Soybean simulated in Brazil 2022 (1000 Ha)

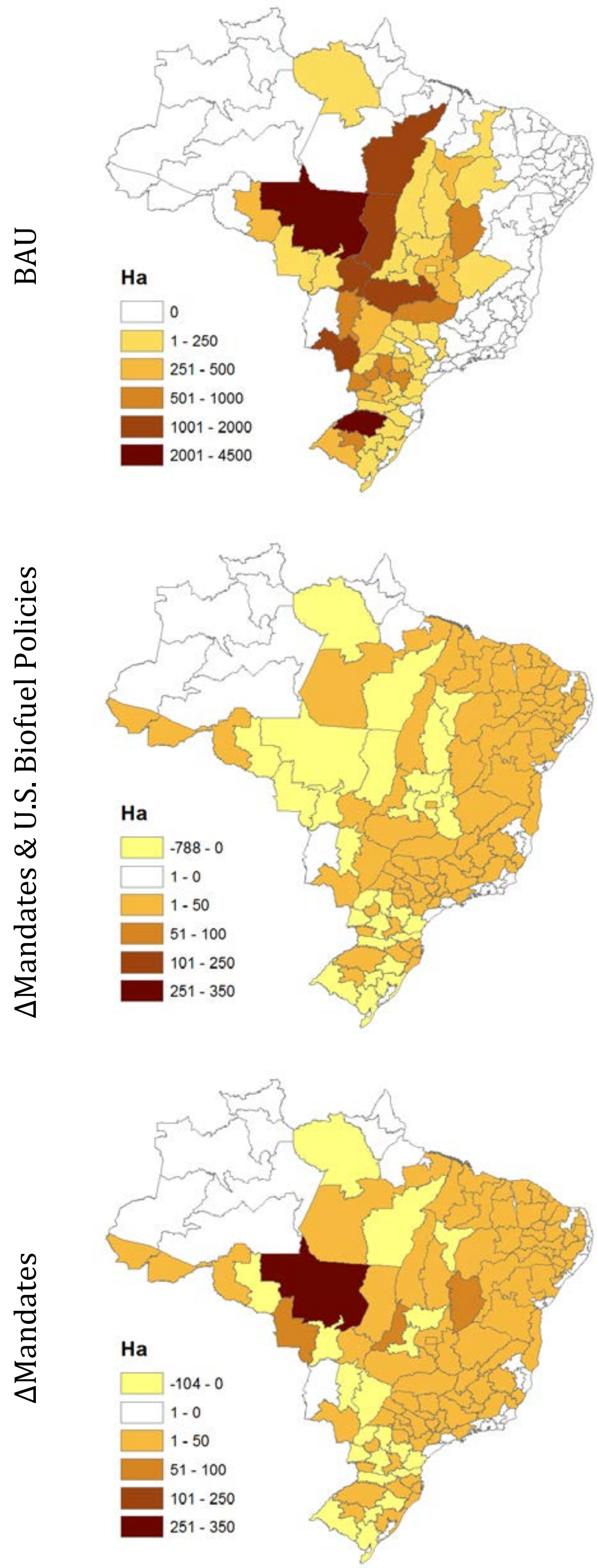
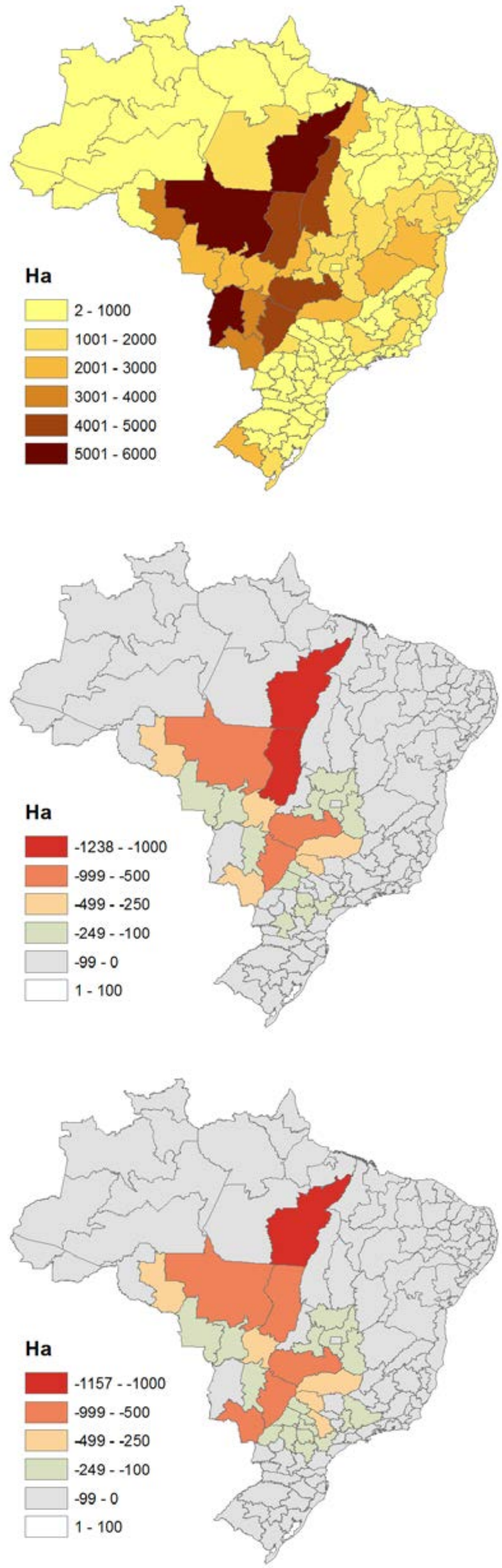


Figure 4.5. Area Total Pasture simulated in Brazil 2022 (1000 Ha)



BAU

ΔMandates & U.S. Biofuel Policies

ΔMandates

Figure 4.6. New Cropland and beef-cattle intensified pastures in 2022 (1000 Ha)

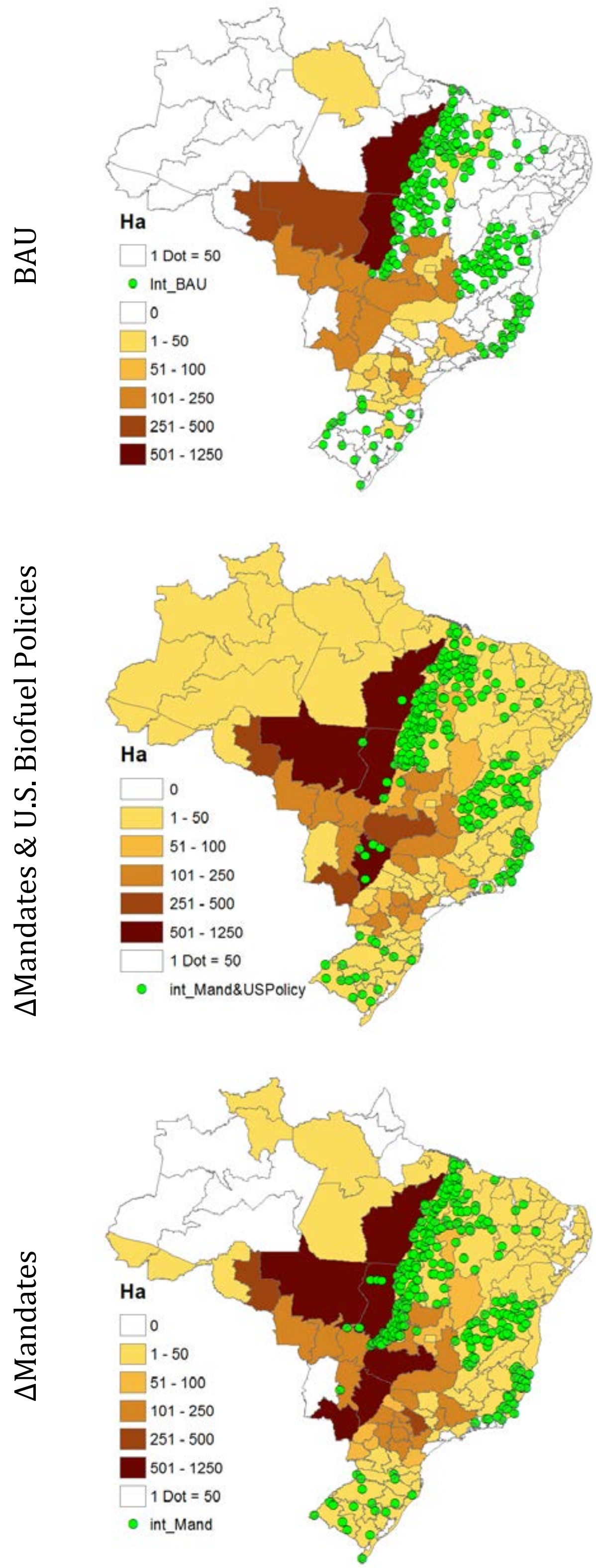
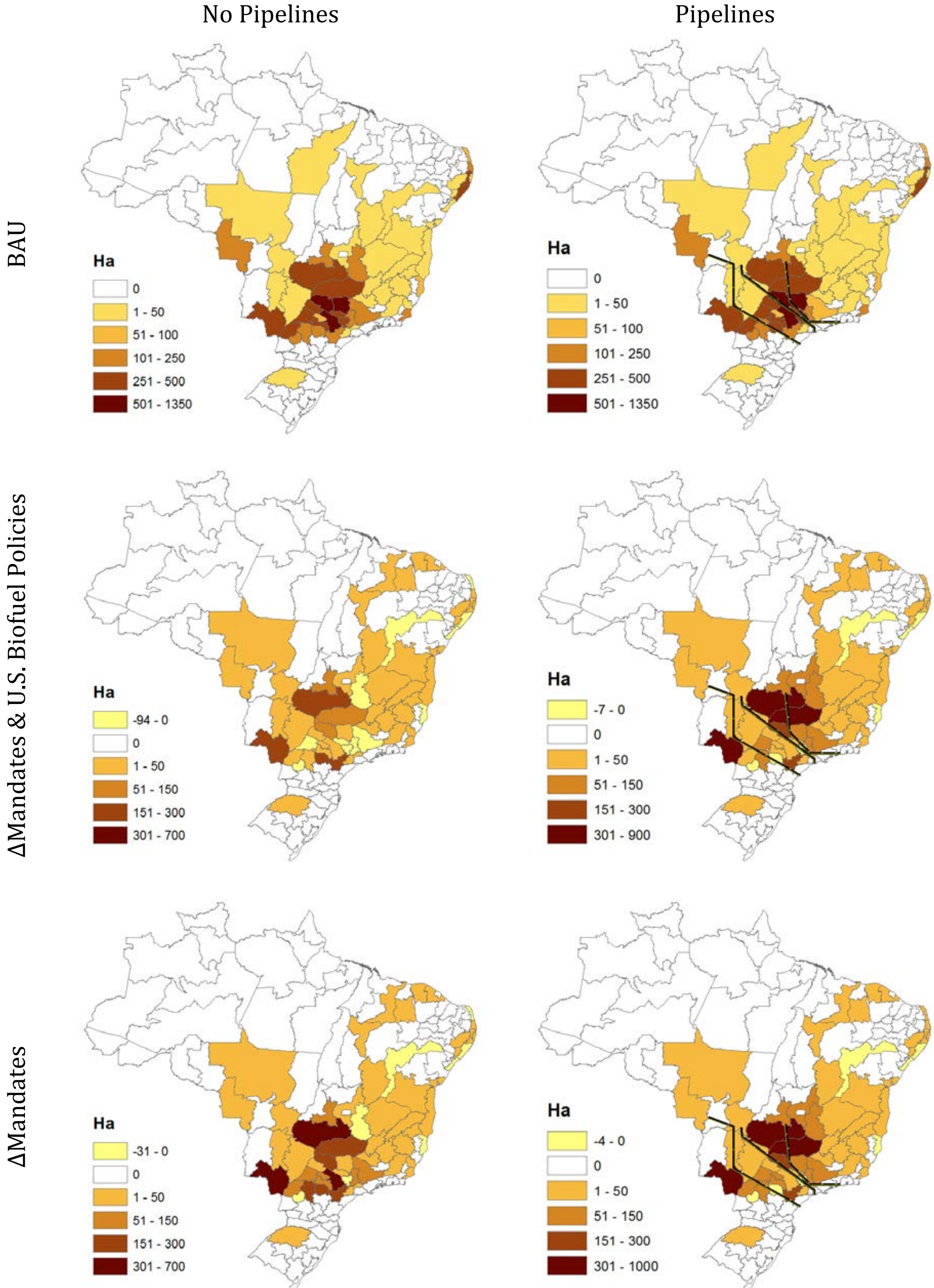


Figure 4.7. Area sugarcane simulated with pipelines in 2022 (1000 Ha)



Tables

Table 4.1. Model Validation Brazil 2007

	Observed	Model	Difference (%)
Land Use (M Ha)			
Total Land	173.15	166.97	-3.57
Corn	13.92	11.27	-19.07
Soybeans	20.52	22.69	10.57
Pasture	127.00	124.43	-2.03
Sugarcane	6.95	6.25	-10.00
Commodity Prices ($/MT)			
Corn	142.25	158.74	11.59
Soybeans	307.80	346.18	12.47
Sugar	420.45	374.35	-10.96
Beef	2,179.25	2,107.91	-3.27
Fuel Sector			
Gas Prices ($/Liter)	1.20	1.14	-4.49
Ethanol Prices ($/Liter)	0.64	0.75	17.39
Gas Consumption (B Liters)	19.18	16.87	-12.06
Ethanol Consumption (B Liters)	16.59	18.65	12.41
Ethanol Exports (B Liters)	3.53	3.96	12.20
Km Consumption (B Kms)	353.00	344.60	-2.38

Table 4.2. Model Validation U.S. 2007

	Observed	Model	Difference (%)
Land Use (M Ha)			
Total Land	122.54	120.93	-1.31
Corn	37.31	36.43	-2.36
Soybeans	25.92	27.02	4.24
Wheat	23.04	22.64	-1.73
Cotton	4.02	4.70	17.08
Commodity Prices ($/MT)			
Corn	155.10	158.46	2.17
Soybeans	328.90	370.38	12.61
Wheat	214.50	247.07	15.19
Fuel Sector			
Gas Prices ($/Liter)	0.72	0.77	7.02
Ethanol Prices ($/Liter)	0.61	0.59	-3.47
Gas Consumption (B Liters)	494.78	507.03	2.48
Ethanol Consumption (B Liters)	26.68	26.60	-0.31
Sugarcane Ethanol Imports (B Liters)	1.77	1.88	6.28
Km Consumption (B Kms)	4,697.52	4,594.09	-2.20

Table 4.3. Model Validation Argentina 2007

	Observed	Model	Difference (%)
Land Use (M Ha)			
Total Land	19.64	18.69	-4.81
Corn	3.58	2.78	-22.39
Soybeans	16.14	15.29	-5.30
Wheat	5.68	5.36	-5.58
Commodity Prices ($/MT)			
Corn	158.80	149.25	-6.02
Soybeans	305.10	353.38	15.82
Wheat	226.40	258.19	14.04

Table 4.4. Effects on the Brazilian Agricultural Sector in 2022

	BAU	Mandates & U.S. Policies	Mandates
Land Use (M Ha)			
Total cropland	49.05	53.19	54.06
Corn	11.76	13.97	13.32
Soybeans	26.33	26.56	26.10
Sugarcane	9.01	10.26	12.46
Pasture	120.03	116.65	115.65
Intensification rate (%)	11.45	11.94	13.87
Crop/Commodity Production (M Ton)			
Corn	61.85	75.32	71.49
Soybeans	79.74	80.40	78.90
Sugarcane	909.20	1,041.88	1,278.26
Sugar	47.90	47.76	47.63
Beef	8.00	7.78	7.79
Soybean Oil	6.01	6.31	6.03
Soybean Meal	26.03	27.34	26.11
Crop/Commodity Exports (M Ton)			
Corn	2.68	18.12	11.96
Soybeans	43.02	42.06	42.12
Sugar	32.90	32.78	32.67
Beef	2.42	2.37	2.37
Soybean Oil	1.09	1.28	1.14
Soybean Meal	6.26	7.93	6.08
Crop/Commodity Prices ($/Ton)			
Corn	175.94	233.63	214.17
Soybeans	462.79	496.66	495.91
Sugar	392.94	403.60	409.41
Beef	11,380.45	13,535.27	13,487.39

Table 4.5. Effects on the U.S. Agricultural Sector in 2022

	BAU	Mandates & U.S. Policies	Mandates
Land Use (M Ha)			
Total cropland	121.30	119.64	122.41
Corn	35.85	36.10	36.32
Soybeans	28.33	26.72	27.28
Wheat	23.23	21.89	22.45
Stover	0.00	23.91	23.26
Straw	0.00	14.96	15.17
Miscanthus	0.55	9.36	6.20
Switchgrass	0.00	0.71	1.06
Crop/Commodity Production (M Ton)			
Corn	374.53	378.45	379.82
Soybeans	94.47	89.20	90.88
Wheat	62.71	60.03	61.35
Soybean Oil	7.92	7.14	7.44
Soybean Meal	34.31	30.92	32.23
Crop/Commodity Exports (M Ton)			
Corn	102.57	78.47	87.22
Soybeans	48.02	47.18	47.17
Wheat	29.93	28.22	29.11
Soybean Oil	0.88	0.67	0.81
Soybean Meal	11.37	9.38	11.29
Crop/Commodity Prices ($/Ton)			
Corn	175.84	233.47	213.74
Soybeans	487.74	521.55	520.86
Wheat	354.89	378.93	368.34

Table 4.6. Effects on the Argentinean Agricultural Sector in 2022

	BAU	Mandates & U.S. Policies	Mandates
Land Use (M Ha)			
Total cropland	19.18	19.17	19.17
Corn	2.97	2.98	2.97
Soybeans	15.47	15.43	15.44
Wheat	5.52	5.51	5.51
Crop/Commodity Production (M Ton)			
Corn	18.40	20.32	20.03
Soybeans	8.07	7.26	7.53
Wheat	10.33	13.08	12.51
Soybean Oil	6.81	6.68	6.71
Soybean Meal	29.52	28.95	29.06
Crop/Commodity Exports (M Ton)			
Corn	10.33	13.08	12.51
Soybeans	43.95	43.19	43.31
Wheat	1.55	1.51	1.52
Soybean Oil	4.00	3.95	3.97
Soybean Meal	28.76	28.21	28.31
Crop/Commodity Prices ($/Ton)			
Corn	166.64	224.25	204.53
Soybeans	477.64	507.64	505.57
Wheat	365.99	390.00	379.43

Table 4.7. Effect on the Brazilian Fuel Sector in 2022

	BAU	Mandates & U.S. Policies	Mandates
Prices ($/Km or $/Liter)			
Km CV	0.08	0.08	0.08
Km FFV	0.07	0.07	0.08
Km EDV	0.10	0.10	0.10
Sugarcane ethanol producer	0.39	0.41	0.42
Gasohol	1.15	1.16	1.16
E100	0.74	0.73	0.75
Production & Exports (B Liters)			
Production Sugarcane Ethanol	45.71	56.63	75.52
Exports Brazilian Ethanol	2.08	15.71	36.54
Exports Brazilian Ethanol thru CBI	0.00	9.27	9.21
Consumption (B Liters or B Kms)			
Km	714.80	714.59	714.09
Gasohol	23.89	26.30	27.82
E100	37.66	34.18	31.94

Table 4.8. Effects on the U.S. Fuel Sector in 2022

	BAU	Mandates & US Policies	Mandates
Prices ($/Km or $/Liter)			
Km CV	0.07	0.07	0.07
Km FFV	0.06	0.06	0.06
Corn ethanol producer	0.54	0.68	0.63
Cellulosic ethanol producer	-	0.85	0.76
Gasohol	0.81	0.73	0.73
E85	0.59	0.53	0.53
Production, Exports & Imports (B Liters)			
Production Corn Ethanol	31.51	53.22	46.68
Production Cellulosic Ethanol	0.00	74.87	60.57
Imports Brazilian Ethanol	0.00	9.42	25.25
Exports U.S. Ethanol	0.00	5.02	0.01
Consumption (B Liters or B Kms)			
Km	5,784.48	5,866.03	5,865.99
Gasoline	489.07	429.06	429.05
Ethanol	31.51	132.49	132.49

Table 4.9. Effect on Social Welfare in 2022 (Δ$B or %Δ)

	Mandates & US Policies (Relative to BAU)	Only Mandates (Relative to "all-inclusive")
GHG Emissions (M Tons CO2-eq)		
Brazil	14.39	6.66
	5.57%	**2.44%**
U.S.	-246.79	27.17
	-13.78%	**1.76%**
Total (Including Arg.)	-232.08	33.79
	-11.24%	**1.84%**
Fuel Producers		
Brazil	1.47	1.56
	5.80%	**5.83%**
U.S.	13.75	-40.49
	6.04%	**-16.77%**
Fuel Consumers		
Brazil	-0.20	-0.70
	-0.02%	**-0.08%**
U.S.	15.50	-0.02
	0.79%	**0.00%**
Agricultural Producers		
Brazil	28.83	7.74
	17.54%	**4.01%**
U.S.	34.19	-16.56
	25.12%	**-9.72%**
Agricultural Consumers		
Brazil	-16.21	1.05
	-4.63%	**0.31%**
U.S.	-22.59	8.68
	-12.24%	**5.36%**
Government Revenue		
Brazil	0.54	0.18
	2.72%	**0.88%**
U.S.	-40.81	48.41
	<100%	**>100%**
Total Welfare		
Brazil	14.44	9.84
	0.99%	**0.67%**
U.S.	0.05	0.01
	0.00%	**0.00%**

Table 4.10. Effect on the Brazilian Fuel Sector including pipelines in 2022

	BAU	Mandates & U.S. Policies	Mandates
Prices ($/Km or $/Liter)			
Km CV	0.08	0.08	0.08
Km FFV	0.07	0.08	0.08
Km EDV	0.10	0.10	0.10
Sugarcane ethanol producer	0.39	0.42	0.42
Gasohol	1.15	1.16	1.16
E100	0.74	0.74	0.74
Production & Exports (B Liters)			
Production Sugarcane Ethanol	46.66	74.68	77.26
Exports Brazilian Ethanol	2.08	34.55	37.93
Exports Brazilian Ethanol thru CBI	0.00	9.17	9.21
Consumption (B Liters or B Kms)			
Km	714.88	714.28	714.09
Gasohol	23.09	26.91	27.52
E100	38.80	33.28	32.38

Table 4.11. Effects on the U.S. Fuel Sector including pipelines in 2022

	BAU	Mandates & U.S. Policies	Mandates
Prices ($/Km or $/Liter)			
Km CV	0.07	0.07	0.07
Km FFV	0.06	0.06	0.06
Corn ethanol producer	0.54	0.62	0.62
Cellulosic ethanol producer	-	0.79	0.76
Gasohol	0.81	0.73	0.73
E85	0.59	0.53	0.53
Production, Exports & Imports (B Liters)			
Production Corn Ethanol	31.46	43.82	45.30
Production Cellulosic Ethanol	0.00	65.45	60.57
Imports Brazilian Ethanol	0.00	34.53	26.64
Exports U.S. Ethanol	0.00	11.30	0.01
Consumption (B Liters or B Kms)			
Km	5,784.44	5,866.02	5,865.98
Gasoline	489.10	429.05	429.05
Ethanol	31.46	132.51	132.49

Table 4.12. Effects on the Brazilian Agricultural Sector including pipelines in 2022

	BAU	Mandates & U.S. Policies	Mandates
Land Use (M Ha)			
Total cropland	49.16	54.05	54.14
Corn	11.76	13.26	13.23
Soybeans	26.35	26.13	26.10
Sugarcane	9.10	12.35	12.65
Pasture	119.92	115.64	115.55
Intensification rate (%)	11.67	14.30	13.93
Crop/Commodity Production (M Ton)			
Corn	61.85	70.80	70.95
Soybeans	79.78	78.97	78.89
Sugarcane	920.51	1,266.74	1,299.17
Sugar	47.90	47.58	47.55
Beef	8.00	7.79	7.78
Soybean Oil	6.01	6.04	6.02
Soybean Meal	26.05	26.18	26.10
Crop/Commodity Exports (M Ton)			
Corn	2.47	10.76	11.26
Soybeans	43.02	42.10	42.12
Sugar	32.90	32.62	32.59
Beef	2.42	2.37	2.37
Soybean Oil	1.09	1.15	1.14
Soybean Meal	6.22	6.05	6.00
Crop/Commodity Prices ($/Ton)			
Corn	175.95	208.14	210.39
Soybeans	462.83	495.54	496.60
Sugar	393.25	410.36	413.37
Beef	11,382.79	13,479.40	13,519.15

Table 4.13. Effect on Social Welfare including pipelines (ΔB$ or %Δ relative to BAU)

	Mandates & US Policies (Relative to BAU)	Only Mandates (Relative to "all-inclusive")
GHG Emissions (M Tons CO2e)		
Brazil	21.01	1.45
	8.21%	**0.52%**
U.S.	-232.48	11.92
	-12.98%	**0.76%**
Total (Including Arg.)	-226.97	13.34
	-11.01%	**0.72%**
Fuel Producers		
Brazil	1.75	0.68
	6.82%	**2.47%**
U.S.	4.92	-32.81
	2.16%	**-14.10%**
Fuel Consumers		
Brazil	-0.74	-0.26
	-0.08%	**-0.03%**
U.S.	15.51	-0.02
	0.79%	**0.00%**
Agricultural Producers		
Brazil	34.65	2.67
	21.07%	**1.34%**
U.S.	17.91	-1.88
	13.15%	**-1.22%**
Agricultural Consumers		
Brazil	-14.75	-0.46
	-4.21%	**-0.14%**
U.S.	-14.56	1.44
	-7.89%	**0.85%**
Government Revenue		
Brazil	0.75	0.06
	3.78%	**0.29%**
U.S.	-38.44	45.91
	<100%	**>100%**
Total Welfare		
Brazil	21.67	2.69
	1.48%	**0.18%**
U.S.	-14.67	12.65
	-0.58%	**0.51%**