Impact of U.S. Biofuel Policy in the Presence of Uncertain Climate Conditions

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Abstract

We analyze the impact of U.S. biofuel policies when crop yields vary due to changes in climate conditions. Our analysis explores scenarios of total and partial waiver of RFS with Monte Carlo simulations for the yields of the main crops in the US. The main model results show that reducing ethanol mandates would make world agricultural consumers better off, and increase U.S. corn share in the world market, while slightly decrease agricultural commodity prices. However ethanol and agricultural producers would face losses and environmental damage increase. Overall RFS reduction generates negative changes in total welfare surplus.

JEL *classification*: Q10, Q48, Q54

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1. Introduction

The increase of the ethanol industry in the U.S. has been the result of a mix of policy and economic factors that have led to use up to 40 percent of the corn crop as input for ethanol production, and about 10 percent of the car-fuel content in the U.S. Considerable effort has been made to assess the social, environmental, and economic impacts of the ethanol boom. Yet, less work has focused on analyzing the effects of biofuel policies under uncertain climate conditions, which affect crop yield throughout all the country.

The interest on weather uncertainty and its relationship with biofuel policy became more salient after the drought of 2012 in the U.S., when the substantial corn price increase brought back the concerns about the role of biofuels on food security and food prices. The U.S. Environmental Protection Agency (EPA) considered a request of a partial or total waiver of the Renewable Fuel Standard (RFS) for 2012 and 2013, but declined it claiming that biofuel policy would not have a significant effect on market outcomes in the short term. In this study we analyze the impact of U.S. biofuel policies when crop yields vary due to changes in climate conditions. We project market conditions to 2022 to allow the markets to adjust to new equilibria, and to match the deadlines of the RFS goals.

Given that the U.S. is the world's largest producer and exporter of grains and oilseeds (USDA-ERS 2012), biofuel policies leading the use of domestic corn for ethanol production have significant implications not only for U.S. crop and livestock production, but also for global trade and international markets. The purpose of this study is to evaluate the effects of the current U.S. biofuel policy (i.e. only RFS mandates), analyzing scenarios of total or partial waiver of RFS in conjunction with uncertainty on the climate conditions via Monte Carlo simulations for each of the main crops' yields in all the agricultural districts from the U.S.

Our analysis encompasses the agricultural and fuel sectors of the U.S. and Brazil, and the agricultural sector of Argentina in a static simultaneous framework, which allows us to examine the changes in the market equilibrium conditions. In addition to bilateral trade between these countries we include the food/feed and biofuel demand of China and the rest of the world (ROW).

We analyze effects on price, land use, main crop/commodity and ethanol markets, and economic surplus of producers and consumers. The main goal is to provide a comprehensive view of the effect of biofuel policies in an environment of climate change uncertainty.[2] The model is calibrated and validated using 2007 as base year, and then we project market conditions to 2022 and introduce uncertainty due to weather conditions by considering alternative parametric distributions specifications for crop yields of the main crops in the U.S. We use the uniform and beta distributions following the related literature (Norwood, Roberts and Lusk 2004; Claassen and Just 2011), and use ranges between yields' historical lowest and highest observed figures for each of the agricultural districts in the U.S. We replicate this model 1,000 times drawing with replacement yields to find the distribution of the variables analyzed in the agricultural and fuel markets scenario in 2022 as well as the more likely scenario, which includes confidence intervals for each of the results. Since RFS level is not a

[2] This paper focuses only on ethanol market and does not incorporate biodiesel production to keep the analysis tractable.

random decision, this application reduce it gradually letting us report results under different mandate levels.

The main model results show that reducing ethanol mandates would make world agricultural consumers better off, and increase U.S. corn share in the world market, while slightly decrease agricultural commodity prices. However ethanol and agricultural producers would face losses and environmental damage increase. Overall RFS reduction generates negative changes in total economic surplus of the related sectors in the model.

2. Background and Previous Work

Ethanol production in the U.S. has been driven by biofuel policy over the last decade, most notably by the regulations on fuels composition under the Renewable Fuels Standard (RFS), which was introduced by the Energy Policy Act of 2005 and later amended by the Energy Independence and Security Act of 2007. RFS established a mandate that requires transportation fuels to contain a minimum amount of fuel from renewable sources each year with a goal of 136.27 billion liters of biofuel production by 2022, with a maximum of 56.78 billion liters of conventional or first-generation ethanol by 2015. Current RFS regulations state that all gasoline-powered vehicles may use a fuel blend with up to 15 percent of ethanol content (E15 or E10), while flex fuel vehicles may use a fuel blend up to 85 percent ethanol content (E85), however, E85 consumption is still very small. As a result, to date, almost 10 percent of car fuel consumption in the U.S. comes from corn-based ethanol (Renewable Fuels Association 2013). In turn, about 40 percent of the corn crop is devoted to ethanol production.[3]

[3] Although the RFS is the central instrument of U.S. biofuel policy, other policy mechanisms including subsidies to ethanol blenders (e.g. the volumetric ethanol excise tax credit), and tariffs to ethanol imports, played a significant role during the development of the ethanol industry but those instruments expired by 2012 (U.S. Farm Bill 2008; Energy Improvement and Extension Act 2008; U.S. International Trade Comission 2011; Energy Policy Act 2005).

Besides biofuel policy, economic considerations also justify the blending of ethanol into gasoline. Babcock (2011) and Babcock (2013) argue that high gasoline prices and the phase out of methyl tertiary butyl ether (MTBE) as oxygenate additive of gasoline in the mid-2000s, also played an important role in the surge of the ethanol industry. As long as ethanol prices are competitive in relation to gasoline, ethanol production is economically viable, even in the absence of the mandate and subsidies.

The economic, social, and environmental effects of the biofuel policy and ethanol production have received substantial attention in the literature. Although the quantification of those effects is confounded by complex and interlinked factors, the increase in corn used for ethanol is regarded as a major driver of crop prices (Gilbert and Morgan 2010; Baffes, Piot-Lepetit and M'Barek 2011; Hochman et al. 2011; Wright 2011), and leading to land and water use changes in the U.S., and in other ethanol and grain producer countries like Brazil and Argentina, where different crops compete for land (Fabiosa et al. 2010; Timilsina et al. 2012; Zilberman et al. 2012). Therefore U.S. biofuel policy becomes a contributing factor in world's agricultural markets.

Also, as identified by Babcock and Zhou (2013), the 2012 drought in U.S. Corn Belt has refocused attention on the purpose of policies that promote the corn ethanol industry. Until recently, weather events associated with climate change did not seem to be a crucial factor for agricultural commodity markets during the ethanol boom, therefore, the literature on the interactions between weather uncertainty and biofuel policy is still in development.

Further, the U.S. Environmental Protection Agency (EPA), the agency in charge of the administration of RFS, has considered several times to issue a partial or full waiver of the Renewable Fuel Standard (RFS). After the drought of 2012, a formal request from Governors from several States was declined by EPA on the grounds that waiving the mandate would have little if any impact on ethanol demand or energy prices over that time period, and no evidence was found of the federal RFS causing severe 'economic harm'. Although the agency recognizes significant hardships in many sectors of the economy created by the drought (EPA 2012). Later, by the end of 2013 EPA announced a preliminary RFS rulemaking for 2014, with a proposal to decrease the ethanol mandate from 14.4 (54.5) to 13 (49.2) billion gallons (liters), acknowledging constraints in the market's ability to consume renewable fuels in coming years at the volumes specified by the Clean Air Act. The proposal has been the subject of heated debate, and the final decision has been delayed longer than the initial deadlines. Roberts and Tran (2013) argue that given that ethanol now accounts for more than 40 percent of the U.S. annual corn harvest together with the current increasing trend of uncertain weather events, it is likely that similar requests to EPA to waive the U.S. ethanol mandate will happen again in the future.

The extent of the influence of a partial of total waiver of the mandate depends on several circumstances, as explained by Babcock (2012), Tyner (2010) Tyner, Taheripour, & Hurt,(2012) and Babcock and Zhou (2013). Ethanol is economically viable, as octane enhancer, and also as a blend, as long as its equivalent energy content is cheaper than gasoline.[4] Therefore, the mandate incentives become relevant under a scenario of low to moderate energy prices, strong export demand, low ethanol stocks, and high corn prices. Crop yield uncertainty may affect the last three.

Several studies have examined the potential effect of a RFS waiver under uncertain crop conditions. Findings from the literature show strong variations depending on the modeling approach, underlying assumptions, and the degree and length of the mandate suspension. Condon, Klemick, and Wolverton (2013) reviewed the current literature on the impact of ethanol policy on corn prices, finding that long-run analyses released between 2008 and 2012 show an average corn price increase between 2 and 3 percent for each extra billion

[4] Ethanol contains about 70% of the energy content of gasoline.

gallons of corn-ethanol in the market. Meanwhile, Carter, Rausser, and Smith (2012) quantified the effect of ethanol production in corn prices using a Structural Vector Autoregression model (SVAR), finding corn prices about 40 percent lower in 2012 without the RFS mandate, concluding that the impact of the U.S. energy policy on global corn prices is considerable, affecting particularly the world's poor.

Roberts and Tran (2013) use a competitive storage model focused on the U.S. domestic market to analyze a suspension of the RFS mandate in 2012 on prices and storage of corn, finding that although a price reduction would only be modest, the reduction in price volatility would be substantial. Furthermore they found high consumer welfare gains associated to lower corn prices in the U.S.

Tokgoz et al. (2008) developed a scenario of short crop with ethanol mandate for 2012-2013. Their results suggest that a decline on the production of corn and soybean would decrease exports and stock levels. As a result, corn exports from South America increase, and the amount of corn fed livestock decreases. However, the effects of the supply shock transmitted to other sectors are considered only temporary. In addition, allowing free trade of ethanol is advisable, since it may attenuate the negative impact of short crops.

Most of the current discussion of the effects of the mandate has centered on price effects and also tradeoffs between corn producers and corn users such as ethanol and livestock producers. In this paper we complement and extend the analysis of the biofuel policies under the weather uncertainty scenarios by looking in the ling-run at effects such as trade, land use, and overall welfare. Further, the U.S. biofuel programs also impact and interact with the rest of the world (Searchinger et al. 2008; Hertel, Tyner and Birur 2010), in our analysis we incorporate other big players of the ethanol and corn markets such as Brazil, Argentina, and China.

3. The model

As a policy analysis tool we use a price endogenous mathematical programming model similar to that in Nunez, Onal and Khanna (2013), but including a module to model the climate uncertainty . The model is a multi-region, multi-market, multi-product, spatial equilibrium model that includes the agricultural and fuel sectors of the U.S. and Brazil, and the agricultural sector of Argentina. In addition to bilateral trade between these countries the food/feed and biofuel demand of China and the rest of the world are also part of the model. Consumers' surplus is derived from consumption of agricultural commodities and transportation fuels by light-duty vehicles that generate vehicle-kilometers-traveled, which generates implicitly the demand for ethanol and gasoline restricted to the technical and policy restrictions.

The model assumes an upward sloping supply function for gasoline in the U.S., ROW, and China components while in the case of Brazil a perfectly elastic supply function is assumed reflecting the constant pricing policy for pure gasoline at the refinery level. The demand and supply functions are assumed to be linear and separable, except the crop supply, modeled in detail at regional level by using Leontief production functions for the U.S., Brazil, and Argentina.

The cost functions include all taxes, subsidies, and marketing margins for fuel demand in Brazil and the U.S. Also, the cost of producing ethanol, co-product credits, the cost of converting new lands from pasture uses to cropland in Brazil and from marginal lands to cropland in the U.S. In addition, the cost of producing energy crops, and the cost of collecting crop residue for conversion to biomass. Further, the cost of processing soybean to soymeal and soy oil, sugar beets and sugarcane to sugar, and the cost of raising beef-cattle in Brazil. Finally, we include internal and external costs of transportation.

The maximization problem is subject to resource limitations, mainly land, policy restrictions, material balance, and technical constraints. Ethanol supply depends on the ethanol productivity of the feedstock (i.e. corn and cellulosic in the U.S. and sugarcane in Brazil) and the feedstock yield, which in turn depends on the region where crop is planted. The model includes a constraint for U.S. biofuel mandates, as implied by the revised RFS (excluding the Biomass-based diesel); feedstock for cellulosic biofuel in the U.S. is assumed to come from corn stover, wheat straw, and from two perennial grasses, namely miscanthus and switchgrass. The agricultural supply side of the model is regionally disaggregated at Crop Reporting District level for the U.S. component, at mesoregion level for Brazil, and at province level for Argentina. In the three regionally disaggregated components, the model includes beef cattle production in Brazil as well as production of corn, sugarcane and thirteen other main temporal crops including soybeans and wheat, allowing commonly practiced intra-year and inter-year crop rotation activities in the three countries. 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.

Commodity supply is the sum of regional production, which depend on the row crop yield and the amounts of land allocated to that crop determined endogenously. The model includes the possibility of a crop-land expansion over pasture land in Brazil. Total land use in each region is restricted to the sum of the total cropland available in the base year, the total pasture land available in Brazil, and the total marginal land available in the U.S.
A detailed mathematical version of the model is presented in the appendix.

To incorporate uncertainty due to weather conditions and its effect on the U.S. agricultural output, we model crop yields distributions. We use uniform and beta distributions. The beta distribution is often used in the crop insurance literature for its flexibility, and relatively satisfactory in-sample and out-of-sample performance (Woodard and Sherrick 2011), and has also been used to model crop yields distributions in the ethanol policy literature (Babcock and Zhou 2013). Data to estimate the parameters of the distributions correspond to yields reported by the U.S. Department of Agricultural (USDA-NASS 2012) at Agricultural District level. Parameters of the beta are obtained following a procedure described in (Woodard and Sherrick 2011). To account for technological change, the data are first detrended against time. Then the trend estimated via Huber M –estimator. Variability is obtained using historical deviations from trend yield and assuming homoscedasticity (Yu and Babcock 2010; Woodard and Sherrick 2011).

Next, we replicate the model 1,000 times drawing with replacement yields from the beta distribution using the estimated parameters. We repeat the same procedure with a uniform distribution taking as the two boundaries the lowest and highest yield in the period 2007-2013 of each crop in each district. Because of the high number of simulations using all crops, we restrict the replications only to the main crops in the U.S. The replication results allow us to find the distribution of the variables analyzed in the agricultural and fuel markets scenarios described in section 5.

4. Data Description

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.

The U.S. crops sector includes sugarcane, alfalfa (semi-perennial crops) and twelve major row annual crops/commodities: corn, soybeans, wheat, sugar beets, barley, sorghum, oats, peanuts, cotton, rice and corn silage. The costs of production for row crops in the U.S. include variable operating costs (seed and treatment, fertilizer, hauling and trucking, drying and storage costs, interest on operating cost), fixed operating costs (limestone, chemical costs, fuel and oil, tractor and machinery, crop insurance, marketing and miscellaneous, stock quota lease, irrigation), capital and overhead costs (machinery and building depreciation cost, interest on investment, overhead), and hired labor costs, while the model determines the land price endogenously.

Similarly, for Brazil, the model considers sugarcane and eight major annual crops: soybeans, corn, wheat, sorghum, cassava, dry-beans, cotton and rice, and beef-cattle production. Finally, for Argentina, the model includes only corn, soybean and wheat. Additionally the model considers processing products from soybean, sugarcane, and sugar beets.

Ethanol is mainly produced in the U.S. from corn and in Brazil from sugarcane. Corn productivity is estimated about 405.35 liters of anhydrous ethanol per ton while sugarcane produces 83 liters of hydrous ethanol and 80 liters of anhydrous ethanol per ton. Corn anhydrous ethanol processing cost is approximately $0.2 per liter, while sugarcane anhydrous ethanol cost is about $0.16. In addition to these costs, the model considers co-product credits, delivering feedstocks costs to refinery, marketing margins, and fuel tax rates. The latter vary across states in Brazil.

For the supply of gasoline in Brazil, the model assumes a fixed price of the pure gasoline at the refinery of $0.525 per liter, which is approximately the sum of refinery price before taxes, market margins of the blenders, and transportation costs from the refinery to the pump.

The VKT demand function is specified for each vehicle type using price elasticities of kilometers driven of -0.2, price per kilometer and total kilometers generated in the base year. The price is obtained by dividing the total cost of fuels consumed by total kilometers generated for each vehicle type. The entire data set, the key supply and demand parameters, are available from the authors upon request.

5. Policy Scenarios and Results

Besides crop yield effects, which reflect weather changes, we aim to analyze the influence of the U.S. biofuel policy on the agricultural and fuel market, in particular the effect of the RFS mandate in 2022.[5] To do so, we project the market conditions to 2022 and simulate eleven different policy RFS scenarios described as follow. First, we assume the full RFS in 2022 is in place (i.e. 56.78 billion liters of conventional ethanol, 75.7 billion liters of advanced biofuel, of which 60.5 billion liters must come from cellulosic biofuel), which will be our reference scenario, and then we assume that RFS is waived by 10 percent gradually until the last scenario, where it is totally waived. For simplicity in tables 1-3, we only report results for every 20 percent change, for example, results in column labeled with 80 percent means changes in the variables of interest due to a 20 percent reduction in the RFS, then column under 60 percent would be a reduction of 40 percent, and so on. Similarly, we only report results for corn and soybean in the U.S. since they are the largest agricultural markets. Thus, these simulations will result in the impact of the U.S. biofuel policy in the presence of uncertain climate condition. Emphasis is placed on land use, main crop/commodity and ethanol markets, and 'quasi-welfare' of producers and consumers. These results are described as follow, but all set of results are available from the authors upon request.

When comparing the base case (full RFS) and the reduced RFS scenarios for corn and soybean markets in the U.S. (table 1 and figures 1-4), we found significant changes arising from a 20 percent and 40 percent RFS reduction. Under those reductions, a substitution effect of 2 million Ha in the all country from corn land to soybean land would drop corn production

[5] The model is calibrated for 2007 policy conditions. Since the actual ethanol consumption in 2007 exceeded the RFS mandate for that year, we do not apply it here. The import tariffs and subsidies remain in place for validation purpose. Validation results are available from the authors upon request. For the policy scenario analysis we remove the import tariffs and subsidies (except by cellulosic ethanol subsidy of $1.01 per gallon) and all scenarios include a minimum ethanol consumption of 3.5 percent of the total fuel consumption as source of octane enhancement.

by 20 million metric tons, while soybean production would increase by 9 million metric tons, mainly for the domestic industry. When comparing results from the uniform and beta distribution, we find low uncertainty on land use since standard errors are small. In the case of the supply, uniform distribution provides a higher uncertainty for corn across all scenarios. For instance, when RFS is reduced by 60 percent corn production would drop by 32.5 million metric tons in average, but after considering the standard error (9.64), this reduction would become significantly higher due to extreme weather conditions. In terms of trade, exports of corn would increase as more corn for ethanol is released, while soybean exports would remain virtually unchanged. Correspondingly, prices of corn would exhibit a considerable reduction ranging from $19 to $23 per ton in the case of the beta distribution but presenting high standard errors that would make this reduction more dramatic, while under the uniform distribution the mean value of the reduction would fall in a wider range ($11 to $41 per ton), but presenting lower standard errors. Similar results would happen to soybean price.

In the U.S. fuel sector (table 2), production and imports (from Brazil) of ethanol drop hand-in hand as the RFS is reduced, however, the standard errors increase as the mandate decreases as seen in table 5. Under the Beta distribution, standard errors for corn ethanol production are small when RFS is reduced by 10 percent and 20 percent, but they become larger when RFS drops further. However, the mean values (about 14 billion liters less) from the scenario under a 30 percent reduction to the non-RFS policy scenarios are not significantly different as displayed in figure 4. In the case of the uniform distribution, production of corn ethanol would drop until RFS is reduced by 50 percent. After this change, reduction would be about 23 billion liters with non-statistical difference at lower scenarios, as shown in figure 4. Therefore we can argue that climate uncertainty would not make a large difference in the production of conventional ethanol in the U.S. if RFS were lower than the current standard.

The first panel in table 3 shows the ‘quasi-welfare’ impact on agricultural consumers of the RFS reduction relative to the benchmark scenario. Agricultural consumer will benefit of RFS reductions because of lower price of corn and soybean (table 2), for the same reason agricultural producers (second panel in table 3) get lower gains. However, in the latter case, results for the U.S. under the beta distribution and scenario under columns 60%-40%-20%-0% show higher standard errors. Therefore risk is increased when weather conditions become variable. However, the uniform distribution appears not able to capture the influence of weather risk. As the mandate is reduced, the fuel sector in the U.S. gets lower gains too due to lower price of ethanol in the case of the producers and less miles consumed by the U.S. drivers. Similarly to the agricultural sector, U.S. fuel producers’ surplus under the beta distribution RFS scenarios exhibits higher standard errors.

Additionally to benefits for agricultural consumers, the U.S. government will also increase its revenue under both distributions and all mandate levels with low uncertainty because it would subsidize less cellulosic ethanol and charge more gasoline volume, which is a more heavily taxed. However, larger consumption of gasoline would bring larger environmental damage in the U.S. In the case of Brazil, since with more ethanol in the domestic market, environmental damage would be reduced.

In sum, when adding up all effects, U.S. and Brazil economic surplus would be negatively affected by the RFS reduction but as the reduction is higher uncertainty would increase due to the high standard errors in these scenarios. Also, risk levels in the U.S. due to uncertain weather conditions also appear to increase when RFS is reduced, particularly when considering beta-distributed crop yields. If we calculate the coefficient of variation as the quotient of the standard error and the point estimate, in the case of corn production, corn prices, soybeans prices, ethanol production, ethanol consumption, gasoline consumption, and economic surpluses, we observe that small reductions of RFS (10%-20%) exhibit changes with low standard errors, and low coefficient of variations, compared to output changes under RFS reductions of 40 percent or above.

6. Discussion

We analyze projected agricultural and fuel market conditions in the U.S., Brazil, and Rest of the World under different U.S. ethanol policy scenarios for year 2022. We account for varying weather conditions that affect crop-yields, and compare a scenario under the status quo of U.S. ethanol policy with alternatives scenarios that relax the ethanol's mandate amount. As empirical tool we use a price endogenous multi-market mathematical programming model to simulate the effects of those scenarios and a Monte Carlo simulation to incorporate the uncertainty of crop yields of corn, soybeans, and wheat in the U.S.

We find a decrease on total economic surplus in the U.S. and Brazil as a result of a reduction of the U.S. biofuels mandate. The bulk of the change occurs when RFS is reduced between 10 percent and 40 percent, with a decrease of about 4 percent of total welfare. After RFS is reduced by more than 40 percent no further significant decrease in total welfare is observed. Therefore, EPA would only require to issue small waivers on the mandate to influence the markets, and after certain threshold any further decrease would be ineffective.

Risk levels in the U.S. due to uncertain weather conditions also increase when RFS is reduced and beta-distributed crop yields are considered. However, as seen in levels most of the increase occurs with RFS waivers up to 40 percent, any reduction beyond does not appear to increase the variability of the results. Reasons behind the lack of response of the U.S. markets to RFS reductions beyond 40 percent can be partly explained by the use ethanol as oxygenate of gasoline, and also by sunk costs already in place by the ethanol industry.

Since RFS reductions increase the consumption of gasoline in the U.S. we find an increase in environmental damage. As mentioned by Babcock (2013) the best way to cut emissions is with carbon taxes applied to all emission sources, still for liquid transportation our results suggest that RFS policy does play a role in the reduction of greenhouse emissions.

In sum, we find an overall gain by maintaining the RFS, agricultural producers are better off with the status-quo, and some reductions in pollution can be achieved, with the caveat that other parts of the ethanol production process may as well generate waste and pollution beyond the assumptions of our model, which can be a limitation of our study, and a motivation for future research.

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8. Appendix

The algebraic representation of the model is given below together with the notation used. The lower case symbols denote exogenous parameters while the upper case symbols represent endogenously determined variables. The subscrits indicate countries and regions while superscripts are used for the type of crop/fuel/commodity. The notation used in the conceptual model is as follows.

Sets in the model:

dom: Brazil, the U.S. and Argentina (Only agricultural sector)
cou: Brazil, the U.S., Argentina, China and ROW
world: China and ROW
r: Regions in Brazil, the U.S. and Argentina
st: States in Brazil
vt: Vehicle type
z: Contains subsets i, j and beef
i: Crop commodities (Corn, Soybean, , Wheat, Corn Silage, Alfalfa, Barley, Beans, Cassava, Cotton, Oats, Peanut, Rice, Sorghum)
j: Processed commodities (Sugar, Soymeal, Soy oil)
beef: Beef in Brazil
c: Feedstocks for ethanol
rc: Row crops
pas: Pasture types
pe: Perennial crops
cr: Crop residues
sys: Livestock systems
act: Livestock Activities

Parameters in the model:

$au_{br,r}^{sys,act,pas}$:	Animal units
$beefc_{br,r}^{sys,act,pas}$:	Cost of raising beef-cattle
$beef\pi_{br,r,r'}^{sys,act,pas}$:	Cost of transportation of calves
$blend_{dom}$:	Minimum blending mandate
$c\square x_{cou}^{z}$:	External costs of transportation
$cla_{dom,r}$:	Total cropland observed available
$crcc_{us,r}^{cr}$:	Cost of collecting crop residues
cw:	Carcass weight
ec^{c}:	Cost of producing ethanol
ecx_{cou}^{c}:	External costs of transportation of exports of ethanol
$e\pi_{dom}$:	Tax rates, subsidies, internal transportation costs, and marketing margins for the ethanol in Brazil
$eyield_{dom}^{c}$:	Ethanol yield from feedstock *c*
γ:	Difference in pure energy contents of ethanol with respect to gasoline
$fr_{br}^{fe,sys,act,pas}$:	Feed requirements
gcx_{cou}:	External costs of transportation of net exports of gasoline
$g\pi_{br}$:	Tax rates, subsidies, internal transportation costs, and marketing margins for gasoline in Brazil
kpl_{dom}^{vt}:	Kilometers per liter
λ_{r}^{t}:	Weight assigned to historical crop mixes
$mla_{us,r}$:	Total marginal land available in the U.S.
$mlcc_{us,r}$:	Cost of converting the marginal land to cropland

$nlcc^{pas}_{br}$: Cost of converting the new land to cropland in Brazil

$pah^{sys,act,pas}_{br,r}$: Convertor from number of cattle heads in the finishing stage to pasture area

$pcc^{pe}_{us,r}$: Cost of producing perennial crops

$pla^{pas}_{br,r}$: Total pasture land observed available in Brazil

$proyield^{i}_{dom}$: Conversion rate of crop *i* to processed commodity *j*

$rcc^{rc}_{dom,r}$: Cost of producing row crops

sc^{i}_{dom}: Cost of processing crops

$\square syield^{c}_{dom,r}$: Feedstock yield

$rcyield^{rc}_{dom,r}$: Row crop yield

$rcyieldn^{\mathrm{rc}}_{br,r}$: Row crop yield in new land

$rfsAdvancedmandate$: RFS advanced ethanol target

$rfscellulosicmandate$: RFS cellulosic ethanol target

$rfsmandate$: RFS ethanol target

sr_{br}: Slaughtered rate

$zaecanapasture_{br,r}$: Pasturelands within Agro-ecological Zoning for Sugarcane

Variables in the model:

$CALV^{sys,act,pas}_{br,r,r'}$: Calves and heifers in Brazil

CD^{z}_{cou}: Demand of commodities *z*

CS^{z}_{world}: Supply of commodities *z*

$CL^{cr}_{us,r}$: Land for crop residues

$CL^{pe}_{us,r}$: Cropland for perennial crops

$CL^{rc}_{dom,\square}$: Cropland

$CS^{i}_{dom,r}$: Crop/commodity supply

CS^{j}_{dom}: Processed commodity supply

$CX^{z}_{xcou,cou}$: Exports of commodities z

ED_{world}: Ethanol demand

ED^{vt}_{dom}: Ethanol demand by vehicle type

$ES^{c}_{\square om}$: Ethanol supply

$EX^{c}_{xcou,cou}$: Ethanol exports

$FEED^{fe}_{br}$: Animal feed commodities

$FS^{c}_{dom,r}$: Feedstock for ethanol

GD_{world}: Gasoline demand

GD^{vt}_{br}: Gasoline demand by vehicle type

$GS_{\square ou}$: Gasoline supply

$GX_{xcou,cou}$: Gasoline exports

$HCF^{sys,act,pas}_{br,r}$: Total number of cattle heads in the finishing stage

$ML^{pe}_{us,r}$: Marginal land for perennial crops

$NL^{pas}_{br,r}$: Pasture converted to new cropland

$NL^{rc}_{br,r}$: New cropland in Brazil

$PL^{sys,act,pas}_{br,r}$: Pasture land

PRO^{i}_{dom}: Processed crops

VKT^{vt}_{dom}: Vehicle Kilometer Traveled

The objective function represents the sum of producers' and consumers' surpluses expressed as follows:

$Maximize$

$$
\begin{aligned}
&\sum_{dom,vt}\int_0^{VKT_{dom}^{vt}} f_{dom}^{vt}(.)\,d(.) + \sum_{cou,z}\int_0^{CD_{cou}^{z}} f_{cou}^{z}(.)\,d(.) - \sum_{world,z}\int_0^{CS_{world}^{z}} f_{world}^{z}(.)\,d(.)\\
&\qquad - \sum_{cou,z}\left(ccx_{cou}^{z}\cdot\sum_{xcou} CX_{xcou,cou}^{z}\right)\\
&+ \sum_{world}\int_0^{GD_{world}} f_{world}(.)\,d(.) - \sum_{cou}\int_0^{GS_{cou}} f_{cou}(.)\,d(.) - g\pi_{br}\sum_{vt} GD_{br}^{vt}\\
&\qquad - \sum_{cou}\left(gcx_{cou}\cdot\sum_{xc\square u} GX_{xcou,cou}\right)\\
&+ \sum_{world}\int_0^{ED_{world}} f_{world}^{c}(.)\,d(.) - \sum_{dom,c} ec^{c}\cdot ES_{dom}^{c} - \sum_{dom}\left(e\pi_{dom}\sum_{vt} ED_{dom}^{vt}\right)\\
&\qquad - \sum_{cou,c}\left(ecx_{cou}\cdot\sum_{xcou} EX_{xcou,cou}\right)\\
&- \sum_{dom,r,rc} rcc_{dom,r}^{rc}\left(CL_{dom,r}^{rc} + NL_{br,r}^{rc}\right) - \sum_{pas} nlcc_{br}^{pas}\cdot NL_{br,r}^{pas}\\
&\qquad - \sum_{r,pe} pcc_{us,r}^{pe}\left(CL_{us,r}^{pe} + ML_{us,r}^{pe}\right) - \sum_{r} mlcc_{us,r}\cdot ML_{us,r}^{pe}\\
&\qquad - \sum_{r} crcc_{us,r}^{cr}\cdot CL_{us,r}^{cr} - \sum_{dom,i} sc_{dom}^{i}\cdot PRO_{dom}^{i}\\
&- \sum_{r,sys,act,pas} beefc_{br,r}^{sys,act,pas}\cdot au_{br,r}^{sys,act,pas}\cdot PL_{br,r}^{sys,act,pas}\\
&\qquad - \sum_{r,r',\square ys,act,pas} beef\pi_{br,r,r'}^{sys,act,pas} CALV_{br,r,r'}^{sys,act,pas}
\end{aligned}
\tag{A1}
$$

The first line of equation (A1) represents the area under the demand curves *f* for *VKT* in Brazil and the U.S. for each vehicle type (first integral) and for agricultural commodities in all countries (second integral) minus the area under the supply functions for imported agricultural commodities. The supply and demand *f* functions are all assumed to be linear and separable. The second line includes the internal and external costs of transportation related to the net exports of agricultural commodities among all countries.

Lines three and four are part of the gasoline module. The first and second integrals are for the areas under the demand curve for gasoline for the *world* and the area under the supply curve of gasoline for all countries. The third term in the third line includes all taxes, subsidies, internal transportation costs, and marketing margins for the gasoline consumed in Brazil, while the fourth line includes the external costs associated with the transportation of net gasoline exports.

The fifth and sixth lines represent the ethanol sector in the objective function. The first integral is the area under the demand curve for ethanol for the *world*. The second term represents the cost of producing ethanol from each feedstock including the price of the co-product from that feedstock weighted by its co-product factor, where biofuel feedstocks includes sugarcane, corn, and cellulosic biomass. The third term includes all taxes, subsidies, internal transportation costs, and marketing margins for the ethanol demand in each country. The fuel demand in Brazil is disaggregated at state level and with a detailed module for fuel transportation (by trucking). The sixth line includes the external costs of transportation associated with ethanol exports.

The lines 7-8 are associated with crop production; the first term in line seven represents the cost of producing row crops in each region on existing croplands and new croplands in the Brazil component. Regions are 137 mesoregions in Brazil, 295 CRDs in the U.S., and 17 provinces in Argentina. The second term in the same line is the cost of converting new lands from pasture uses to cropland, where the cost depends on the three pasture types, namely 'pasture planted in good condition', 'pasture planted degraded' and 'native pasture'. The third term in line seven is the cost of producing perennial crops on croplands and marginal lands, where the two perennial crops are miscanthus and switchgrass. The first term in line eight is the cost of converting marginal lands to cropland. The eighth line includes also the cost of collecting crop residue (i.e. corn stover and wheat straw) for conversion to biomass. The last term in line eight is the cost of processing soybean to soymeal and soy oil and sugar beets and sugarcane to sugar.

The last two lines in equation (A1) are related to the beef-cattle module in Brazil. The first term is the annual cost of raising beef-cattle, measured in animal units, which depends on the total amount of pasture land in each system, activity, and pasture type. The systems are the extensive and semi-intensive and the activities contain three ranching practices, namely finishing, complete cycle and weaning. The second term represents the transportation costs of calves from weaning to finishing ranches among regions depending also on the system, activity, and pasture type.

The maximization of problem (A1) is subject to several constraints labeled by A2-A23. Consumers in Brazil and the U.S. obtain utility from vehicle kilometer traveled (*VKT*), which is produced from gasohol consumption, i.e. gasoline blended with anhydrous ethanol at specified blending rates. While ethanol-gasoline blending is limited to 10 percent in the U.S. and 20-25 percent in Brazil, flex fuel vehicles can consume any proportion up to 100 percent (E100). The latter vehicle type is included only in the Brazil component. The total driving distance generation (*VKT*) results from the kilometers that can be driven per liter of each fuel type and specified differently for each vehicle type; *VKT* it is assumed to be proportional to the amount of fuel consumed by each vehicle category, as shown in equations A2-A4:

$$VKT_{dom}^{vt} \leq kpl_{dom}^{vt}(\gamma ED_{dom}^{vt} + GD_{dom}^{vt}) \qquad \forall\, dom, vt$$

(A2)

The model restricts the consumption of E100 to FFVs and EDVs in Brazil, while the consumption of E85 is restricted to FFVs in the U.S. Gasohol can be consumed by both FFVs and CVs in both countries.

Equation (A3) represents the minimum blending mandate for gasohol, which is 25 percent for Brazil (in the base case scenario) and 3.5 percent in the U.S. Recall that EDVs can consume E100 only, so they don't require this constraint.

$$ED_{dom}^{vt} \geq blend_{dom}(ED_{dom}^{vt} + GD_{dom}^{vt}) \qquad \forall dom, For\ vt = CV, FFV \tag{A3}$$

Finally, equation (A4) restricts the use of E85 to only FFVs in the U.S., which contains 85 percent anhydrous ethanol and 15 percent gasoline.

$$ED_{us}^{FFV} \leq 0.85(ED_{us}^{FFV} + ED_{us}^{FFV}) \tag{A4}$$

Equations (A5) and (A6) represent the national gasoline and ethanol balances, respectively. Recall that set *c* is used to distinguish which feedstock is used for the ethanol (i.e. sugarcane, corn, or cellulosic biomass).

$$\sum_{vt} GD_{dom}^{vt} + GD_{world} \leq GS_{cou} + \sum_{xcou} GX_{xcou,cou} \qquad \forall cou \tag{A5}$$

$$ED_{world} + \sum_{vt} ED_{dom}^{vt} \leq \sum_{c} ES_{dom}^{c} + \sum_{xcou} EX_{xcou,cou}^{c} \qquad \forall cou \tag{A6}$$

Equations (A7) and (A8) express the ethanol supply whose production depends on the ethanol productivity of the respective feedstock and on the feedstock yield. Cellulosic feedstock includes biomass from perennial crops and crop residues.

$$ES_{dom}^{c} = \sum_{r} eyield_{dom}^{c} \cdot FS_{dom,r}^{c} \qquad \forall dom \tag{A7}$$

$$FS_{dom,r}^{c} = fsyield_{dom,r}^{c} \cdot \left(CL_{dom,r}^{c} + NL_{br,r}^{c} + ML_{us,r}^{pe}\right) \qquad \forall dom, r, c \tag{A8}$$

The supplies of two crop residues, corn stover and wheat straw, are restricted to the total area planted for corn and wheat.

Equations (A9)-(A11) represent the U.S. biofuel mandates, as implied by the revised RFS (excluding the Biomass-based diesel). Specifically, the model requires that 132.5 billion liters of ethanol must be blended with gasoline, of which 60.5 billion liters must be cellulosic biofuel and 75.7 billion liters must be advanced biofuel (excluding Biomass-based diesel) which may include sugarcane ethanol imported from Brazil:

$$\sum_{vt} ED_{us}^{vt} \geq rfsmandate \tag{A9}$$

$$ES_{us}^{cellulosic} \geq rfscellulosicmandate \tag{A10}$$

$$EX_{BR,US} + ES_{us}^{cellulosic} \geq rfsAdvancedmandate \tag{A11}$$

In the simulation, these are the equation whose right hand side is reduced progressively (by 10 percent) to show the effect of a change in the RFS. Equation (A12) expresses the agricultural commodity balances. The constraint states that consumption commodity z, feed demand for the livestock sector in Brazil, and net exports cannot exceed the supply of that commodity.[6]

$$CD_{cou}^{z} + FEED_{br}^{fe} + \sum_{xcou} CX_{xcou,cou}^{z} \leq CS_{cou}^{z} \qquad \forall cou, z \tag{A12}$$

Commodity supply in equation (A12) is the sum of regional production which depend on the row crop yields ($rcyield_{dom,r}^{rc}$) and the amounts of land allocated to that crop. The latter is determined endogenously as shown in equation (A13). The model includes a crop land expansion possibility in Brazil. Row crop production variables on both the existing crop lands and expansion (new) lands determine the supply of crop commodities.

[6] In the U.S. feed uses of corn and soybean meal are augmented to the total domestic consumption variables since a detailed U.S. livestock sector is not included in the model.

$$CS_{dom,r}^{i} = \sum_{r} rcyield_{dom,r}^{rc} \cdot CL_{dom,r}^{rc} + \sum_{REG} rcyieldn_{br,r}^{\mathrm{rc}} * NL_{br,r}^{rc} \qquad \forall dom, z \tag{A13}$$

To include in the model the uncertainty due to weather conditions and its effect on the U.S. agricultural output, we replicate the model 1,000 times drawing with replacement row crop yields from an uniform distribution between the lowest and highest yield in the period 2007-2013 of each crop in each district. We repeat same procedure with a Beta distribution, for which we estimate the parameters alpha and beta in a previous step for each crop and district. Due to the high number of simulations using all crops, we restrict the replications only to the main crops in the U.S., namely corn, soybean and wheat. Equation (A14) represents the production of processed commodities, where the processed amount of crop determines the supply of processed commodity.

$$CS_{dom}^{j} = \; pr\square yield_{dom}^{i} \cdot PRO_{dom}^{i} \qquad \forall dom \tag{A14}$$

The land use in each region is restricted to the sum of the total cropland available in the base year, the total pasture land available in Brazil, and the total marginal land available in the U.S.

$$\sum_{rc,pe} \left(CL_{dom,r}^{rc,pe} + NL_{br,r}^{rc} + ML_{us,r}^{pe} \right) + \sum_{sys,act,pas} PL_{br,r}^{sys,act,pas} \leq \square la_{dom,r} + \sum_{pas} pla_{br,r}^{pas} + mla_{us,r} \quad \forall dom, r \tag{A15}$$

As equation A15 implies, the perennial grasses can be grown on marginal lands and/or croplands. However, the model restricts the cropland allocated to perennial grasses not to exceed 25 percent of the total cropland availability in each region in order to prevent extreme specialization in the production of perennial grasses.

All new land in Brazil that can be used for crop production must come from the pasture lands in each region. Pasturelands allocated to beef-cattle production under all systems and activities and the converted lands cannot exceed the total amount of pastures available in each region (equations A16).

$$\sum_{sys,act,pas} PL_{br,r}^{sys,act,pas} + \sum_{rc} NL_{br,r}^{rc} \leq \sum_{pas} pla_{br,r}^{pas} \qquad \forall\, r \tag{A16}$$

The model allows sugarcane expansion in Brazil only on the pasturelands within Agro-ecological Zoning for Sugarcane (*Zaecanapasture*) that are suitable for its expansion (equation A17).

$$NL_{br,r}^{sugarcane} \leq zaecanapasture_{br,r} \qquad \forall\, r \tag{A17}$$

The 'crop mix' constraint is represented by equation (A18). This approach prevents unrealistic changes and extreme specialization in land use. The symbol λ_r^t is a non-negative endogenous variable which represents the weight assigned to the historical crop mix observed in each region at year *t*. Equation (A19) states that the sum of these weights must be less than or equal to 1 (convexity requirement).

$$CL_{dom,r}^{rc,pe} \leq \sum_{t} \lambda_r^t \cdot cla_{dom,r}^t \qquad t: 2003, \ldots, 2009 \quad \forall\, r, rc \tag{A18}$$

$$\sum_{t} \lambda_r^t \leq 1 \qquad t: 2003, \ldots, 2009 \quad \forall\, r \tag{A19}$$

Finally, equations A20-A23 describe the beef-cattle production options in the Brazil module. Beef supply is obtained from the total number of cattle heads in the finishing stage converted to Animal Units (450 kg) and carcass weight (approx. 50 percent) taking into account that not all cattle in this stage are slaughtered in one year (slaughtered rate). *Heads Cattle finished* include cattle received in finishing from weaning farms as well as that in complete cycle farms (equation A20).

$$CS_{br}^{beef} = \sum_{r,sys,act,pas} cw \cdot sr_{br} \cdot au \cdot HCF_{br,r}^{sys,act,pas}$$

(A20)

As cattle production is transformed from extensive to semi-intensive system, feed requirements will increase. The model assumes that feed comes only from soymeal and corn. The key parameter here is $au_{br,r}^{sys,act,pas}$ which is the number of animal units that can be raised per unit of pasture area in each farm type (equation A21) and determines the total herd size that each farm can have. This relationship is defined for each system, range activity, and type of pasture.

$$FEED_{br}^{fe} = \sum_{r,sys,act,pas} fr_{br}^{fe,sys,act,pas} \cdot au_{br,r}^{sys,act,pas} PL_{br,r}^{sys,act,pas} \; \forall f\square$$

(A21)

Equation (A22) relates the total cattle stock (in heads) in each region to the pasture area equivalent. The key parameter here is the pasture area ($pah_{br,r}^{sys,act,pas}$) required per unit of cattle in the finishing stage, which is defined for each system, range activity, and type of pasture. The related information is obtained again from AgraFNP (2008a) and extrapolated to all regions based on the agricultural census (2006).

$$PL_{br,r}^{sys,act,pas} = pah_{br,r}^{sys,act,pas} \cdot HCF_{br,r}^{sys,act,pas} \qquad \forall\, r, sys, act, pas$$

(A22)

where $HCF_{br,r}^{sys,act,pas}$ includes the heads sent from weaning to finishing ranches.

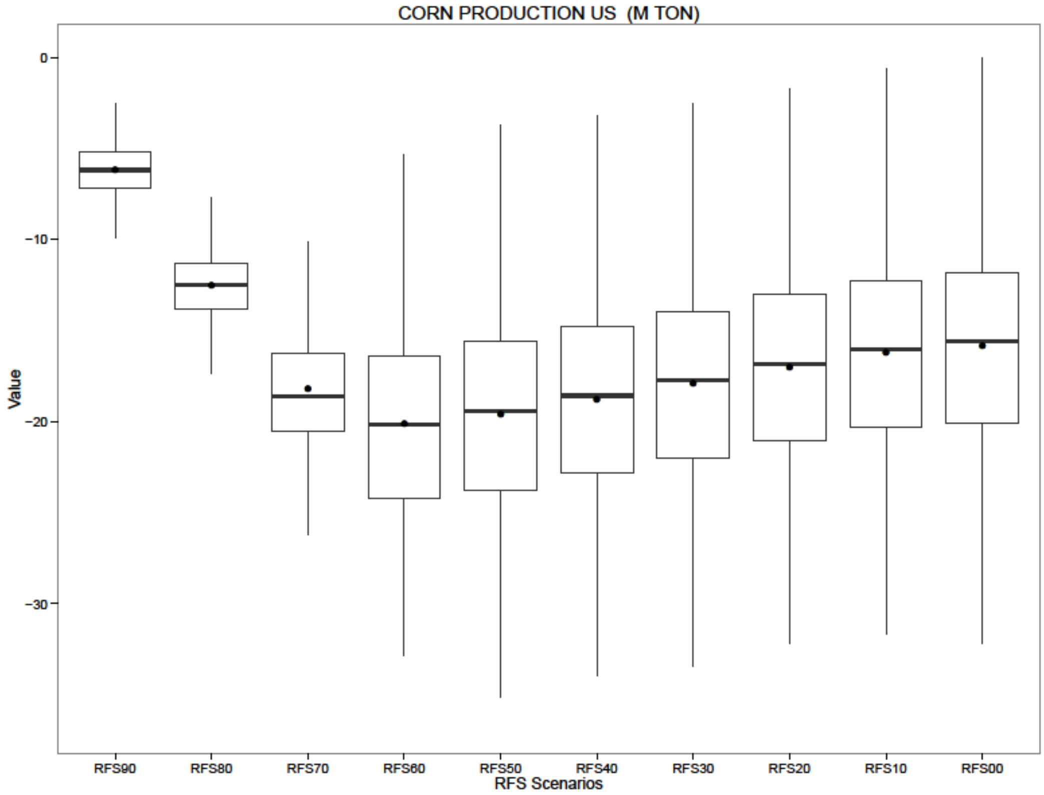
To close the module, equation (A23) restricts the pasture area in the model by type of pasture (planted, degraded, and native) to be less or equal that the total pasture land availability observed in the base year in each region.

$$\sum_{sys,act} PL_{br,r}^{sys,act,pas} \leq pla_{br,r}^{pas} \qquad \forall\, REG, Pasture$$

(A23)

Figure 1. Corn Production in the U.S., 2022 (Change respect to full RFS)

Beta distribution



Uniform distribution

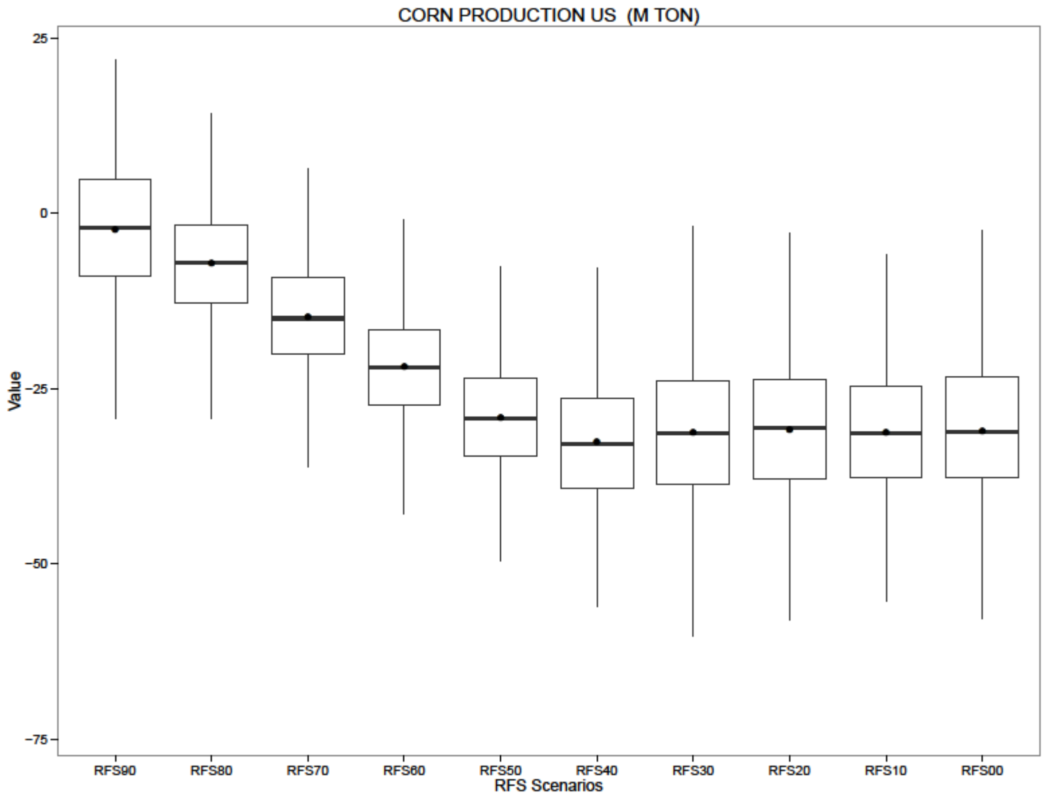
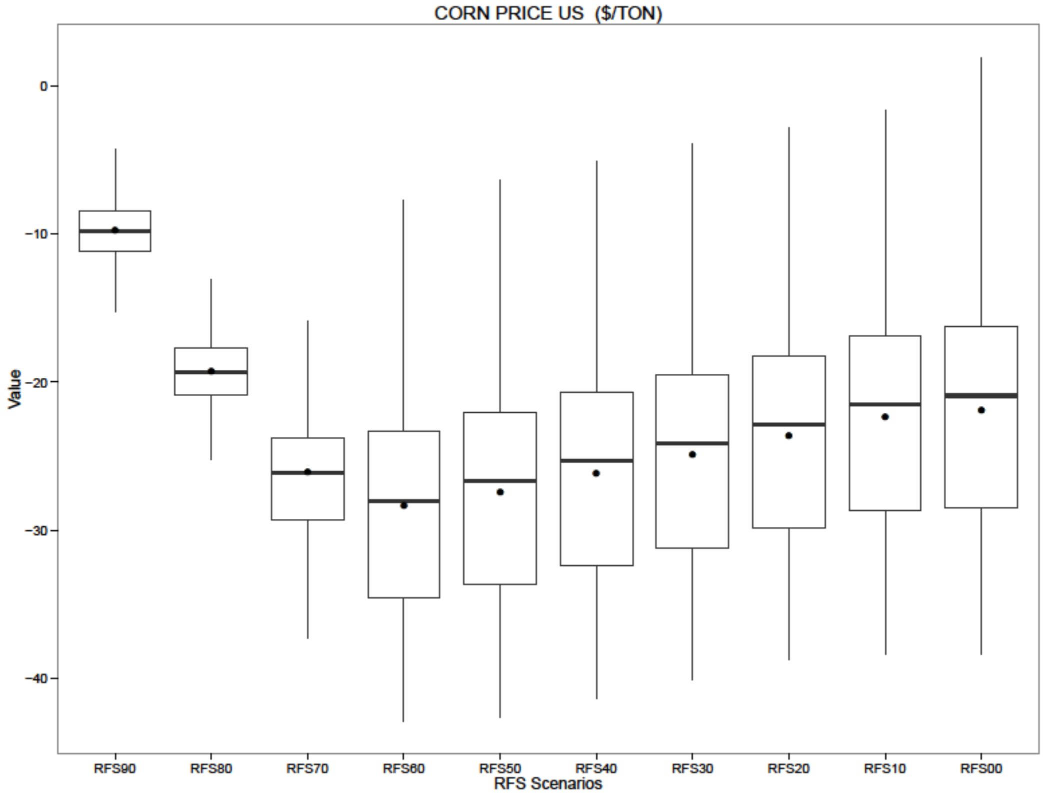


Figure 2. Corn Price in the U.S., 2022 (Change respect to full RFS)

Beta distribution



Uniform distribution

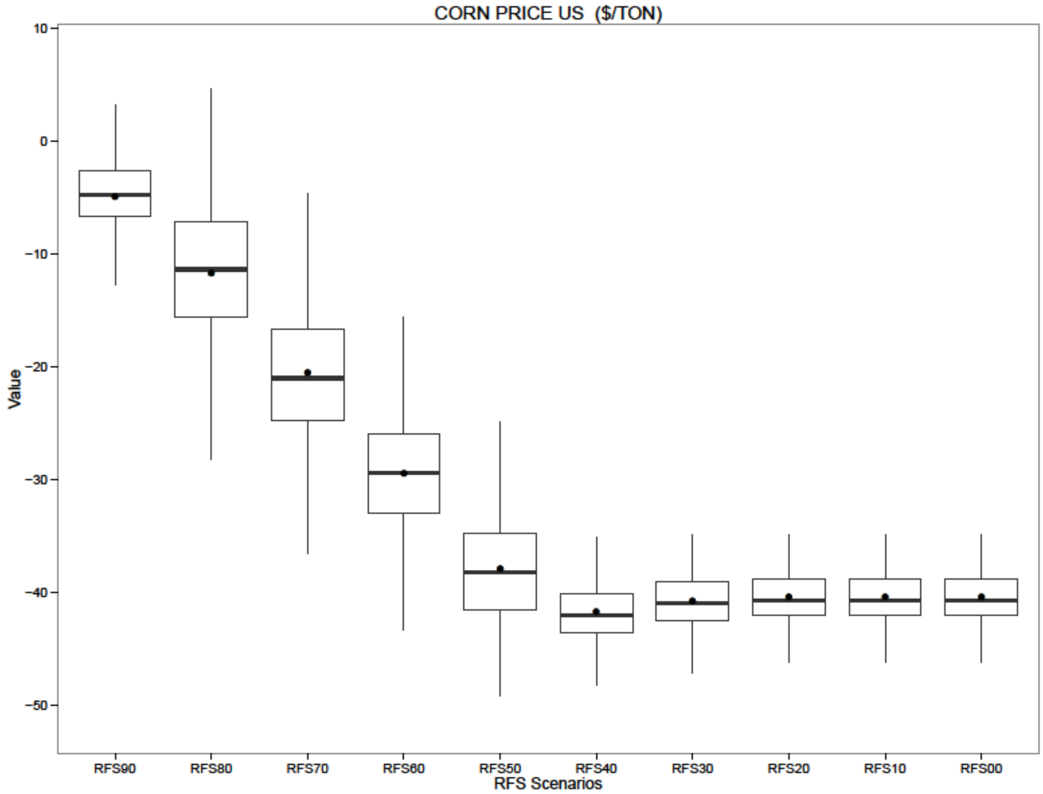
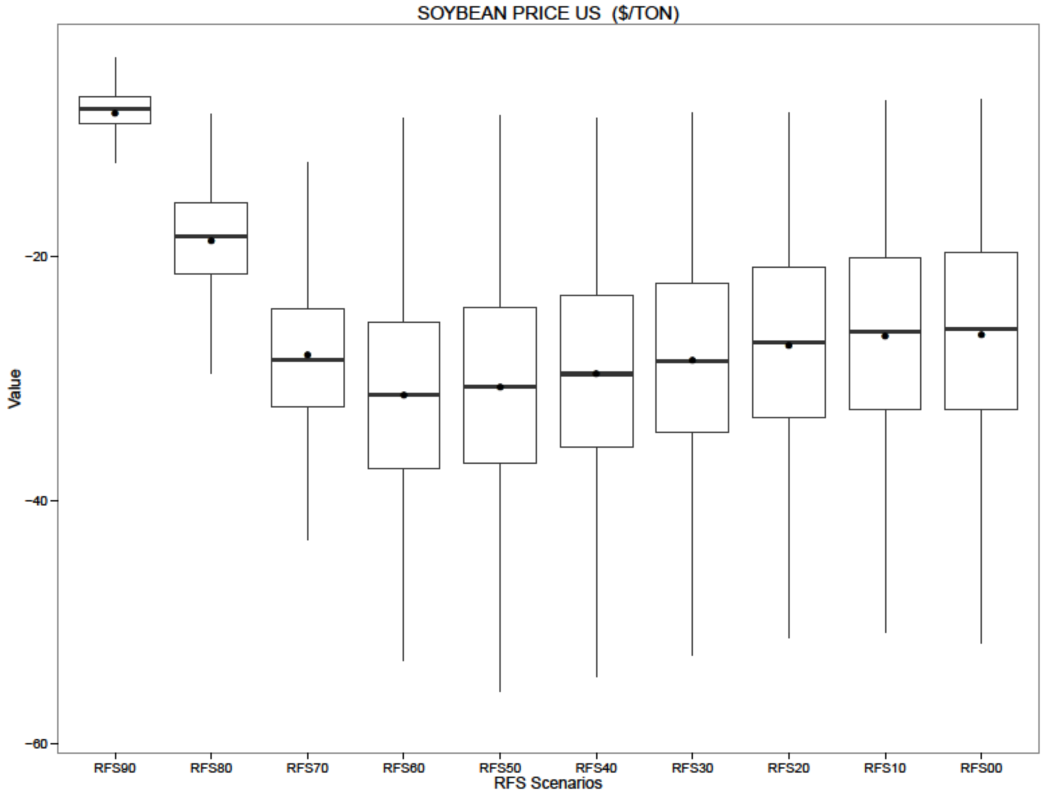


Figure 3. Soybean Price in the U.S., 2022 (Change respect to full RFS)

Beta distribution



Uniform distribution

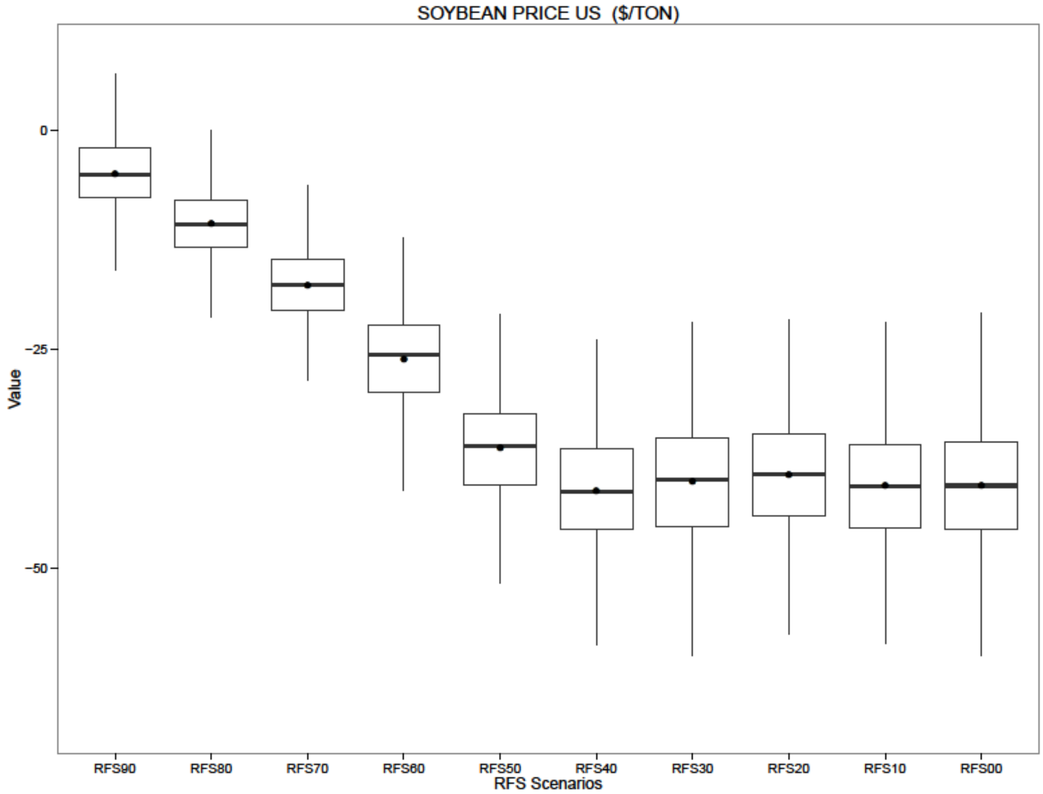
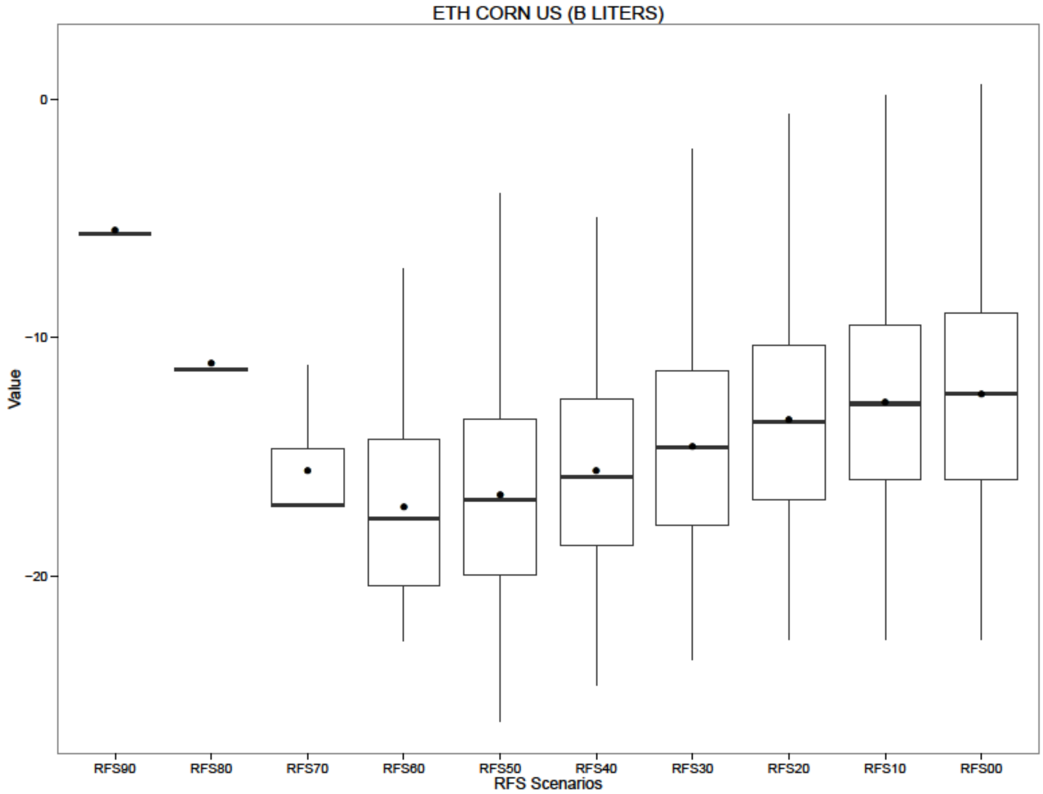


Figure 4. Corn ethanol production in the U.S., 2022 (Change respect to full RFS)

Beta distribution



Uniform distribution

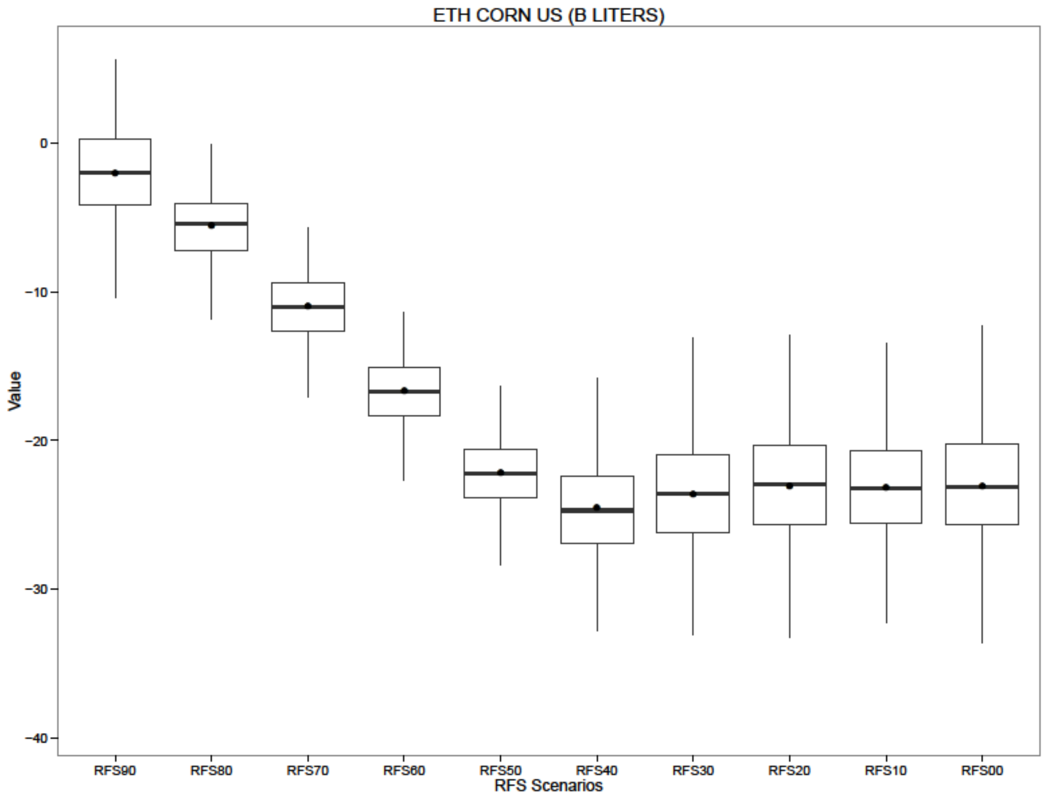


Table 1. U.S. Agricultural Sector

	Beta					Uniform				
RFS Change[a]	80%	60%	40%	20%	0%	80%	60%	40%	20%	0%
Corn										
Land Use (M Ha)	-1.17	-1.91	-1.77	-1.60	-1.48	-0.69	-2.31	-3.37	-3.22	-3.24
	[.19]	[.55]	[.59]	[.59]	[.61]	[.44]	[.41]	[.46]	[.5]	[.51]
Production (M Ton)	-12.56	-20.15	-18.76	-17.03	-15.86	-7.11	-21.86	-32.50	-30.86	-31.01
	[1.95]	[5.19]	[5.56]	[5.55]	[5.79]	[8.36]	[8.02]	[9.64]	[10.08]	[10.39]
Exports (M Ton)	6.29	9.54	8.07	5.64	4.96	1.48	6.09	9.41	8.07	8.08
	[1.42]	[2.28]	[2.19]	[2.3]	[2.48]	[.82]	[1.91]	[.56]	[.33]	[.32]
Price ($/Ton)	-19.28	-28.32	-26.12	-23.62	-21.94	-11.71	-29.50	-41.72	-40.40	-40.39
	[2.47]	[7.33]	[7.93]	[7.91]	[8.34]	[5.64]	[5.27]	[2.53]	[2.08]	[2.08]
Soybean										
Land Use (M Ha)	1.67	2.38	2.30	2.18	2.14	1.37	2.93	3.74	3.66	3.75
	[.22]	[.46]	[.49]	[.49]	[.51]	[.46]	[.44]	[.44]	[.44]	[.46]
Production (M Ton)	0.45	0.70	0.68	0.64	0.62	4.95	11.06	14.46	14.07	14.34
	[.05]	[.15]	[.16]	[.16]	[.17]	[2.18]	[2.12]	[2.11]	[2.13]	[2.22]
Exports (M Ton)	6.49	9.37	8.99	8.47	8.25	0.31	0.72	1.02	0.99	1.01
	[.85]	[1.97]	[2.11]	[2.1]	[2.19]	[.12]	[.13]	[.14]	[.14]	[.15]
Price ($/Ton)	-18.66	-31.35	-29.66	-27.33	-26.44	-10.75	-26.10	-41.13	-39.35	-40.56
	[3.97]	[8.21]	[8.74]	[8.51]	[8.81]	[4.19]	[5.56]	[6.76]	[6.95]	[7.27]

Notes: Standard errors are reported in brackets [ ]. [a]Results are the average difference with respect to full RFS, for example in the row labeled “land use” under corn, -1.17 means a reduction of -1.17 million Ha of planted corn when RFS is reduced is 80% of the current RFS from 2022.

Table 2. U.S. Fuel Sector

	Beta					Uniform				
RFS Change[a]	80%	60%	40%	20%	0%	80%	60%	40%	20%	0%
Production										
Cellulosic (Billion liters)	-12.11	-24.23	-35.85	-45.58	-56.57	-12.11	-24.13	-35.13	-45.54	-56.25
	[.]	[.]	[.31]	[.1]	[.42]	[.]	[.23]	[.21]	[.05]	[.05]
Corn (Billion liters)	-11.11	-17.12	-15.57	-13.43	-12.38	-5.58	-16.63	-24.48	-23.03	-23.10
	[.77]	[3.88]	[4.13]	[4.25]	[4.54]	[2.53]	[2.35]	[3.35]	[3.81]	[3.94]
Price ($/liter)	-0.05	-0.07	-0.06	-0.06	-0.05	-0.03	-0.07	-0.10	-0.10	-0.10
	[.01]	[.02]	[.02]	[.02]	[.02]	[.01]	[.01]	[.01]	[.01]	[.01]
Trade										
Imports (Billion liters)	-3.03	-6.06	-9.58	-14.98	-15.14	-3.03	-6.15	-10.29	-15.03	-15.14
	[.]	[.]	[.31]	[.1]	[.]	[.]	[.23]	[.21]	[.05]	[.]
Exports (Billion liters)	0.18	0.18	0.18	0.18	0.18	5.77	6.09	6.09	6.09	6.09
	[.63]	[.63]	[.63]	[.63]	[.63]	[2.53]	[2.35]	[2.35]	[2.35]	[2.35]
Consumption										
Ethanol (Billion liters)	-26.43	-47.59	-61.17	-74.18	-84.26	-26.50	-53.00	-76.00	-89.69	-100.58
	[.48]	[4.06]	[4.4]	[4.53]	[4.47]	[.]	[.]	[2.45]	[3.11]	[3.13]
Gasoline (Billion liters)	15.77	28.40	36.51	44.27	50.41	15.81	31.63	45.35	53.89	61.15
	[.28]	[2.43]	[2.63]	[2.7]	[2.83]	[.]	[.]	[1.46]	[2.06]	[2.09]
Gasohol Price ($/liter)	0.02	0.03	0.04	0.05	0.06	0.02	0.04	0.06	0.06	0.06
	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]

Notes: Standard errors are reported in brackets [ ]. [a]Results are the average difference with respect to full RFS.

Table 3. Social Economic Surplus Effects

		Beta					Uniform				
	RFS Change[a]	80%	60%	40%	20%	0%	80%	60%	40%	20%	0%
Agricultural Consumer	US	7.01	10.16	9.64	8.99	8.57	4.75	9.55	13.16	12.78	12.83
		[.58]	[1.86]	[2.03]	[2.02]	[2.14]	[1.21]	[1.16]	[.77]	[.81]	[.81]
	Brazil	3.07	5.54	5.67	5.67	5.31	2.72	5.33	8.06	8.36	8.34
		[.77]	[.71]	[.62]	[.62]	[.71]	[.78]	[1.05]	[.75]	[.71]	[.71]
Agricultural Producers	US	-15.36	-21.72	-18.73	-15.47	-13.21	-10.63	-20.32	-26.09	-23.25	-22.07
		[1.39]	[4.14]	[4.58]	[4.54]	[4.87]	[1.73]	[1.48]	[1.33]	[1.77]	[1.78]
	Brazil	-5.05	-10.06	-12.44	-15.26	-14.88	-8.24	-13.88	-20.18	-23.18	-23.25
		[.92]	[.98]	[1.02]	[1.01]	[1.14]	[2.41]	[2.58]	[2.36]	[2.34]	[2.34]
Fuel Consumers	US	-3.65	-6.30	-7.87	-9.29	-9.69	-3.66	-6.94	-9.48	-8.87	-5.81
		[.06]	[.49]	[.49]	[.47]	[.67]	[.]	[.]	[.26]	[.83]	[.89]
	Brazil	-0.03	0.10	0.27	0.41	0.40	0.23	0.32	0.57	0.73	0.73
		[.04]	[.03]	[.03]	[.03]	[.03]	[.13]	[.13]	[.12]	[.12]	[.12]
Fuel Producers	US	-31.64	-48.08	-46.97	-44.33	-44.84	-20.12	-47.80	-64.38	-64.29	-68.44
		[2.01]	[8.78]	[9.34]	[9.64]	[10.57]	[4.02]	[3.81]	[4.73]	[5.91]	[6.12]
	Brazil	-3.30	-3.79	-4.71	-4.51	-2.83	-5.59	-6.53	-7.41	-2.19	8.71
		[.62]	[.54]	[.58]	[.62]	[2.32]	[1.47]	[.96]	[.96]	[3.1]	[3.3]
Goverment Revenue	US	5.45	9.73	12.22	14.27	16.53	4.53	9.96	14.47	16.82	19.34
		[.15]	[.89]	[.92]	[.97]	[.97]	[.42]	[.39]	[.68]	[.81]	[.83]
	Brasil	-0.51	-0.51	-0.51	-0.50	-0.50	-0.51	-0.59	-0.59	-0.58	-0.58
		[.09]	[.09]	[.09]	[.09]	[.09]	[.13]	[.]	[.]	[.]	[.]
Environmental damage	US	58.01	100.04	133.13	164.45	188.76	61.89	107.96	149.69	182.70	209.71
		[1.19]	[3.85]	[4.29]	[4.4]	[4.86]	[2.6]	[2.55]	[3.5]	[4.56]	[4.5]
	Brasil	-5.70	-6.85	-7.96	-9.16	-8.79	-7.04	-9.23	-10.75	-10.67	-8.09
		[.87]	[1.12]	[1.2]	[1.17]	[.97]	[1.6]	[.81]	[.77]	[1.02]	[1.07]
Total Surplus	US	-55.60	-86.22	-91.66	-95.16	-99.27	-43.70	-87.95	-117.22	-121.63	-127.06
		[2.76]	[11.7]	[12.64]	[12.88]	[13.3]	[4.06]	[3.67]	[5.53]	[6.42]	[6.56]
	Brasil	-4.11	-6.66	-9.34	-11.44	-9.86	-9.28	-12.58	-16.31	-13.67	-3.63
		[.62]	[.71]	[.83]	[.83]	[1.9]	[2.52]	[2.28]	[2.27]	[3.51]	[3.7]

Notes: Standard errors are reported in brackets [ ]. [a]Results are the average difference with respect to full RFS.