IMPACT OF LARGE-SCALE BIOFUELS PRODUCTION ON CROPLAND-PASTURE AND IDLE LANDS

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Abstract

An important criticism of the indirect land use change (ILUC) estimates of biofuels to date is that they have not accounted for the presence of marginal lands such as cropland-pasture and idle-lands. This paper offers a novel framework for analyzing the impact of biofuels production on these marginal lands. The methodology includes the steps involved in identifying and incorporating marginal land data such as area under cropland-pasture and idle lands such as U.S. Federal Conservation Reserve Program (CRP) enrolled land into the database, computing the associated land-rents which imply productivity of land, and specifying the marginal lands in the land supply function in a computable general equilibrium model. Two policy scenarios are examined in this study: 1) implementing U.S. and EU biofuel mandates for 2015 and 2) implementing the corn-ethanol only mandate by 2015 in the U.S. These policy experiments also look at the potential implications of releasing or fixing the CRP land enrollment by the USDA on global land-use and land-cover changes. The results revealed that though accessibility of these marginal lands dampens large shifts in cropping patterns, the ILUC emissions measured in terms of grams of CO_2 equivalent per MJ of biofuel produced, were significantly affected mainly due to increase in deforestation when the cropland-pasture is used for cultivation of crops. Future research to more accurately characterize the productivity of these marginal lands will be needed.

JEL Classification: C68, Q18, Q23, Q24, Q42, R14

Keywords: Biofuels, computable general equilibrium (CGE), Agro Ecological Zones (AEZs), land use change, marginal lands, idle lands, cropland-pasture, conservation reserve program (CRP).

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1. Introduction

As biofuels emerge as one of the important alternate fuels of the 21st century, they also necessitate huge demand for feedstocks putting added pressure on land use. The only possible ways to meet both food and fuel demands are by intensifying agriculture on current croplands or by expanding the cropland area (expansion at the extensive margin). Several studies have raised concerns about environmental and social impacts of biofuel programs. Kelly (2007) estimated that the increased biofuels production in the U.S. could lead to a shift in cropping patterns towards corn, and it could bring marginal land prone to erosion, forest, pasture land etc. under corn[2]. Since biofuels are generally pursued as cleaner fuels supporting climate change mitigation, the land-based greenhouse gas (GHG) emissions resulting from production of biofuel feedstocks is decisive, particularly if the growing demand for biofuel feedstock is met by extensification. Biofuels produced by accessing the additional land covers such as forest and pastureland which typically involves burning of above ground biomass and tilling the soil, result in release of carbon in to the atmosphere. This emission is regarded as the indirect land use change (ILUC) emission, and it has drawn vital attention lately. Indeed, this has been the most controversial element of the U.S. Environmental Protection Agency (EPA) regulation. The ILUC issue was a key bargaining chip in the recent climate change bill. Several proponents of first generation biofuels argue that the science on measuring life cycle emissions of biofuels is rudimentary and must be improved.

Since accounting for ILUC includes world-wide conversion of forest and grassland to cropland in response to higher commodity prices, it has been strongly debated across the biofuel industry and among researchers. The U.S. EPA estimated the GHG emissions from renewable fuels using life-cycle analysis. The corn-ethanol produced at a typical natural gas dry mill plant was found to reduce CO_2 equivalent emissions by 16% over a 100 year time period, but the same emission increased by 5% over a 30 year time period (USEPA, 2009). The key contributing factor in these emissions is the magnitude of international (indirect) land use change resulting from producing the renewable fuels. The recent adoption of the Low Carbon Fuel Standard

[2]For example, Kelly (2007) reports that California's state law stipulates to increase the share of alternative fuels from the current 6% to 20% by 2020 and 30% by 2030. This might require cutting down distant forests to grow biofuel feedstocks consequently exacerbating the global warming.

(LCFS) by the California Air Resource Board (CARB) requires that the transportation fuels supplied to California market should meet at least 10% declining standard of carbon intensity[3]. CARB's measure of carbon intensity for biofuels includes emissions from indirect land use change and this is sufficient to rule out corn-ethanol as a low carbon fuel in California. CARB requires that estimates of the world-wide conversion of forest and grassland to cropland in response to higher commodity prices be included while assessing the carbon intensity of biofuels.

Studies on land-use competition from production of biofuels' feedstock have also drawn attention of using *degraded* / *idle* / *marginal* lands. Though these terms are often used synonymously, we adopt the term *marginal* land, as a summary of all land which is not as productive as the regular cropland, which may be due to soil topography, water scarcity, poor management practices, etc. With the increasing national targets for biofuel production across the world, several studies have emphasized the potential pressure on these marginal lands to grow biofuel feedstocks (Dufey, 2007; Fargione *et al.*, 2008; Kløverpris *et al*., 2008; Pagel 2008). Since changing vegetation on these marginal lands influences the GHGs-flux, it is important to understand the indirect impact of biofuels production on these lands. Keeping this in view, in this study we identify and incorporate the potential marginal lands into the model and estimate the global land-use and land-cover implications of biofuel expansion on the marginal lands.

2. Analytical Framework

In order to analyze the world-wide land-use implications of biofuels in the presence of marginal lands, we utilize the GTAP-BIO developed by Birur *et al*. (2008). The land supply framework in the GTAP-BIO model follows Lee *et al*. (2005), where the land endowment is broken into 18 Agro-Ecological Zones (AEZ) so as to yield a more accurate representation of sectoral competition for land. As offered by Hertel *et al.* (2009), a nested constant elasticity of transformation (CET) function is adopted, in which land-owners maximize return to land by allocating land in two tiers (Figure 1). The land supply function is nested in the value added nest of the firms' production structure which follows constant elasticity of substitution (CES) form.

[3] http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

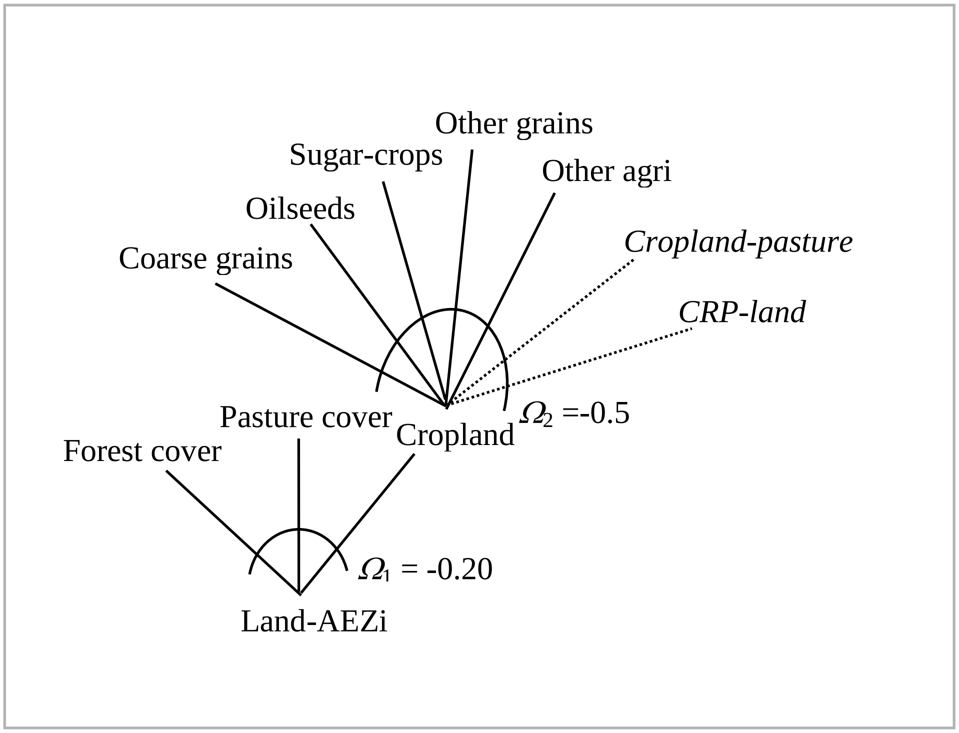


Figure 1. Land Supply in the GTAP-BIO Model.

In the first stage, the land-owner makes optimal allocation of a given parcel of land under crops, pasture or commercial forest, while the choice of crops is made in the second stage (five categories of crops: coarse grains, oilseeds, sugar-crops, other grains, and other agriculture). The ease with which the land in a given AEZ_i is transformed across uses is governed by the elasticity of transformation, which will be discussed in Section 4.1. One important observation to be made here is that the only way any given crop can expand is by displacing other sectors. However, in reality, a crop can expand to other lands, called *marginal lands*, depending on the biophysical availability.

Literature survey indicates that studies on analyzing implications of marginal lands in a general equilibrium framework are scarce. However, Gurgel *et al*. (2007) offer some novel approaches of introducing land in a CGE framework. Those authors utilize MIT Emissions Predictions and Policy Analysis (EPPA) model, a recursive-dynamic multi-sector CGE model with 16 regions, and analyze the land use implications of producing cellulosic biofuels. Those authors disaggregate the agricultural sector into crops, livestock, and forestry sub-sectors and allow for conversion of land across five land types: cropland, pastureland, harvested forestland, natural grassland, and natural forestland. Those authors deviate from the CET approach since it is share preserving in nature and not appropriate for longer term analysis, and introduce a cost of conversion approach. The advantage of this approach is that, the model keeps track of conversion costs and value of the timber stock resulting from conversion. However, Gurgel *et al*. treat land as one endowment without accounting for any heterogeneity such as AEZ classification. Though the dynamic approach of the model is useful for longer term projections, the model is not suitable for short or medium term analysis and also cannot track location of land use change within a given region.

Van Meijl *et al*. (2006) and Eickhout *et al*. (2008) have introduced a framework that combines an economic model (LEITAP) and a biophysical model (IMAGE) for estimating the productivity of marginal lands. The IMAGE model calculates the productivity of seven food crops at 0.5^o grid level. The overall productivity is expressed on a scale of 0 to 1 on the basis of potential crop productivity. When the grid cells are ordered from low to high productivity in each region, we can get a land productivity curve. The inverse of the land productivity curve determines the land supply curve for that region. Those authors introduce these land supply curves with the assumption that most productive land is used first in production. If the gap between agricultural land that is potentially available and land actually used in agriculture sector is large any increase in demand for land would lead to a modest increase in price (as the land conversion is easy at this stage). However, if the land in use is close to the total potentially available land, any increase in demand will lead to greater increase in land rent and also land conversion becomes difficult. The authors then use this land rent data for econometrically estimating the parameters of the land supply curves required by the LEITAP model. This approach takes into account detailed biophysical information, but does not allow for explicit competition for land at the AEZ level. Therefore, we follow an alternative approach of finding the additional categories of cropland that is idle in reality and may be brought under cultivation. This approach permits us to retain the fixed land endowment.

2.1 Incorporating Marginal Land Data

As more attention is being paid on the potential use of marginal lands, equally challenging for researchers is to identify and access this land. For instance, in the U.S., the marginal lands that can be brought under cultivation of food/feedstock crops are cropland-pasture (pasture-crop), idle cropland, rangeland, uncultivated horticultural areas, etc. Lubowski *et al.* (2006) report a snapshot at land-use changes between 1982 and 1997, and found that most of the changes from cultivation to uncultivation and vice versa were registered in cropland-pasture and Federal Conservation Reserve Program (CRP) lands. Therefore, we choose to include (a) cropland pasture and (b) Idle croplands in our land supply function. As Lubowski *et al.* define; "*idle croplands*" in the U.S. include land cover under soil-conserving uses and cropland enrolled in the Federal CRP and Wetland Reserve Program (WRP). In contrast, "*cropland-pasture*" unlike permanent grassland pastures, is considered to be in long-term crop rotation which is marginal for crop uses. Since data on these idle-land and cropland-pasture data are not available at the AEZ level, we obtained the county/regional level data for the U.S. and Brazil from several sources such as University of Tennessee, Oak Ridge National Laboratory, etc (Table 1). These regional data were approximately mapped to the AEZ level, and we modified the land cover data to account for these missing categories of land.

In this study we pay special attention to marginal lands in the U.S. and Brazil, as both are leading producers of biofuels with vast implications on land-use and land-cover change. By using historical land-use data, satellite imaging, and ecosystem models, Campbell *et al*. (2008) estimated the global extent of abandoned cropland and pastureland that can be used to grow biofuel feedstock crops. Their study revealed that, at the national scale, the U.S., Brazil and Australia have the largest area of abandoned crop and pasture lands, which offer immense potential for biofuel crops. Also, as evident from Table 1, both U.S. and Brazil possess substantial areas of marginal lands that may be brought under cultivation of biofuel feedstock crops. In the U.S., total cropland includes three broad categories: cropland used for crops (this includes harvested cropland, crop failure, and summer fallow), idle cropland, and cropland pasture (Figure 2). As seen from Table 1, about 40 million acres of *idle land* (CRP + other idle lands) and 62 million acres of cropland-pasture in the U.S. has been brought into the data base.

In the case of Brazil, cropland-pasture area of about 58 million acres was incorporated into the data base. For all other regions in the world, based on the estimates of previous studies, we assume a region-specific range of 1 to 10% of pastureland area as the acreage under cultivated cropland-pasture. The Food and Agricultural Organization of the United Nations estimates that the global area of pasture-cover and fodder/pasture-crops together is about 8.6 billion acres in 2000, which is about 27% of total land area (FAO, 2008).

Table 1. Land Cover data with New Categories of Land in the U.S. and Brazil.

(million acres)

Land Cover Type	USA			Brazil		
	SAGE	NASS, ERS/USDA	*Modified*	SAGE	ORNL	*Modified*
Crop-cover	454	442	454	127	124	124
Forest-cover	835	651	835	389	-	389
Pasture-cover	573	587	573	447	378	378
Unmanaged land	276	228	276	401	-	401
Total	**2137**	1908	**2137**	**1365**		**1293**
Harvested Area	326	340	326	120	-	120
Cropland-pasture (U of T)	56	62	62	-	58	58
CRP[+] Land (U of T)	28	40	40	-	-	-
Total	410	442	428	120		168

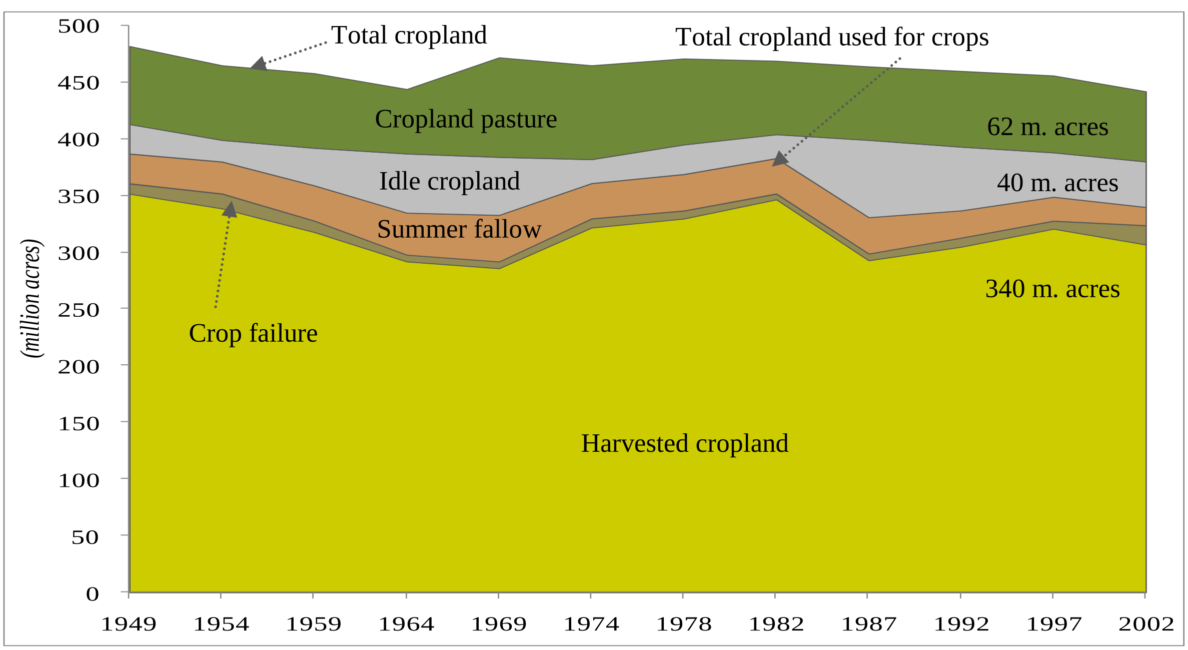
Note: For *modifying* land cover data, CRP[+] lands, cropland-pasture data were obtained from various sources:

SAGE: Center for Sustainability and the Global Environment, University of Wisconsin-Madison, contributes to the GTAP land-use data base at the global level.

ORNL: Pasture-crop data for Brazil was provided by the Oak Ridge National Laboratory, TN.

U of T: University of Tennessee, Knoxville, provided U.S. country level data on idle lands and pasture-crop area, which was used for mapping at the AEZ level.

U.S. land cover data from SAGE is compared with the data reported by NASS, ERS-USDA.



Data Source: Lubowski *et al.* (2006).

Figure 2. Major uses of Cropland in the U.S. (million acres)

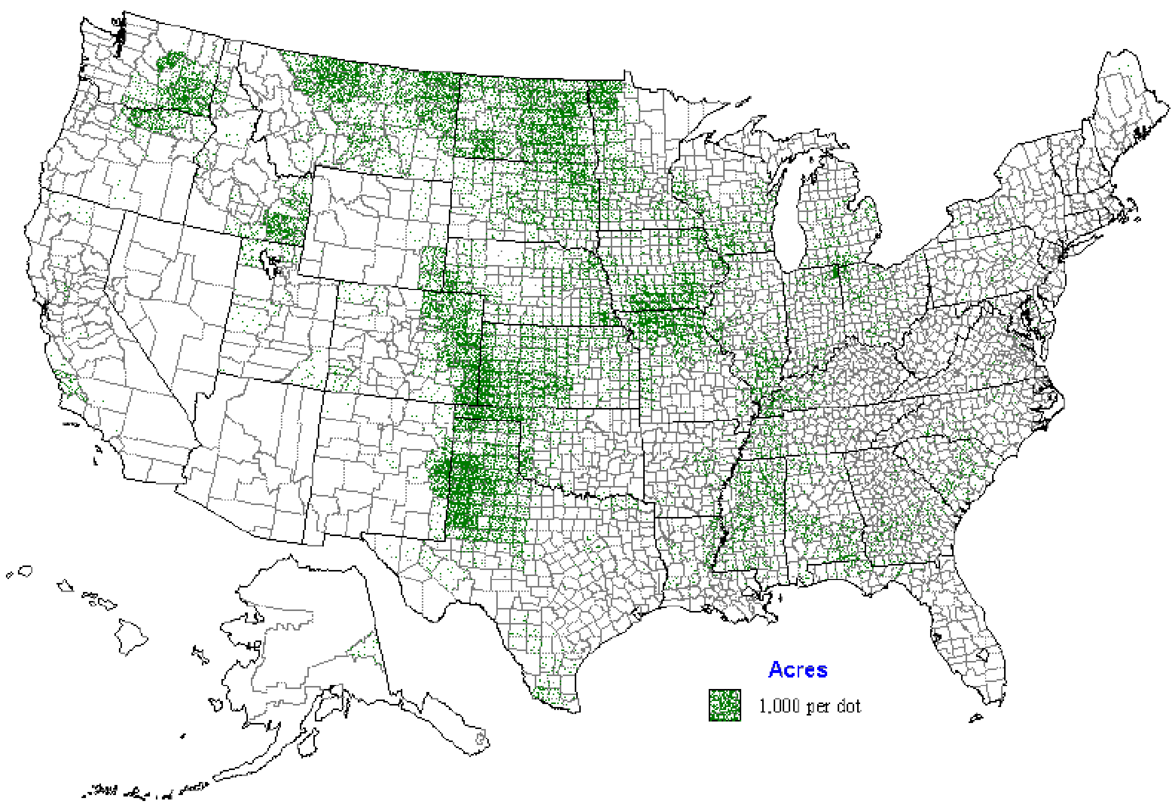
In this study, we make a distinction between pasture-cover and cropland-pasture (area under fodder-crops). Based on the FAO (2008) data on harvested area of fodder crops, we assume about 10% of pasture-cover as area under cropland-pasture in Canada and Europe, 6% in Latin American countries excluding Brazil, 1 to 3% in Asian countries, and 1% or less for African countries.

A thirty-year trend analysis of the cropland-pasture area from 1980 through 2000 by FAO (2008) indicates that the cropland-pasture acreage in South America has decreased by half between 1980 and 2000, partially due to an increase in soybean area. The Eastern Africa region also experienced a major decline in pasture area, due to large scale conversion in to agricultural land. However area under cropland-pasture has slightly increased in Europe over the same time period, because of its "set-aside" policy measure which, in the past required farmers to keep a certain fraction of their land (about 10%) under fallow in return for receiving direct payments. Alternatively, farmers could cultivate non-food crops such as pasture-crops on the set-aside land under a "non-food on set-aside" regime. Keeping these findings in view, incorporating cropland-pasture area for all the regions strengthens the analysis of this study.

2.2 Accessibility of CRP Lands in the U.S.

Though the CRP was originally was designed to reduce soil erosion and commodity surpluses (Osborn, 1993), it has subsequently resulted in other environmental benefits such as preserving wildlife habitat, water quality, soil carbon sequestration, etc (Best *et al*. 1997; Sullivan *et al*. 2004). CRP rewards farmers with annual rental payments and cost-share assistance. The data that we have utilized in this study pertains to the agricultural year 2000. Of the 455 million acres of farm land in the United States, the CRP enrollment across 3144 counties in the U.S. was about 34 million acres (7.5% of cropland). The county-wise distribution of CRP-acreage is shown in Figure 3. After mapping the county-level data into AEZ level, the crops compete directly for acreage in CRP land in a given AEZ.

The U.S. Department of Agriculture has a budget estimate of $1.8 billion to be distributed over 430,000 farms, at an average of $50.93/acre, in the FY 2009. However, the Food, Conservation, and Energy Act (Farm Bill) of 2008, extends the CRP enrollment authority through September 30, 2012[4]. The enrollment authority has set the target of 39.2 million acres through 2009 and this will be reduced to 32.0 million acres for fiscal years 2010, 2011, and 2012. What determines any early withdrawal of land from CRP and voluntary enrollments are the commodity prices, cost of production, and the relative payments to potential income. Currently, there are severe penalties associated with premature CRP withdrawal – such as full reimbursement of federal payments and a penalty of 25% of total payments received. In this study we examine the potential impact of two policy options: (a) USDA adjusts the rental rates offered in order to ensure a constant CRP total land area and (b) USDA does not adjust rental rates, thereby allowing some CRP land to be released.



Source: FSA (2003)

Figure 3. Distribution of CRP Acreage in the U.S. (2000).

[4] Similar to CRP for cropland, the USDA also administers the Grassland Reserve Program (GRP) for protecting the grasslands and conserving the biodiversity of plants and animal populations in the U.S. The Farm Bill of 2008 has set an increase in enrollment under GRP by 1.22 million acres during 2009-2012, from the current 115,000 acres. In this study we have not included the GRP land.

2.3 Computing Land Rents for Marginal Lands

As discussed earlier, the land rents are the indicators of productivity in each AEZ. In the GTAP data base, Lee *et al*. (2009) share out land rents for cropland, pasture-cover and forest-cover based on the yearly economic activity in a given AEZ. They determine cropland rents based on value of crops produced in a given AEZ using 0.5^{o} grid level data on crop area harvested and per hectare yield data offered by Monfreda *et al.* (2008), and prices from FAOSTAT. The temperate AEZs with longer length of growing period (LGP) found to have the highest land rents worldwide, followed by the tropical AEZs, and then boreal zones. Also, the land rents are largest in those AEZs where high value crops such as vegetables, fruits and nuts, and irrigated crops such as paddy-rice, sugarcane, etc. are grown.

For determining land rents for the livestock sector which includes the economic activities of ruminants (cattle, sheep and goats), dairy production, wool, and non-ruminants (pigs and poultry), Lee *et al*. draw on the direct competition between these sectors with the grazing land. For this purpose, they utilize land cover (pasture cover) data provided by Ramankutty *et al.* (2008) which explicitly shows the availability of pasture/grazing land in each AEZ for all the regions in the world. For computing livestock sectors' land rent, Lee *et al.* use the average coarse grain yield in each AEZ (as there is no 'forage crop' sector in the GTAP data base) and multiply it by the pasture land cover hectares. Overall, the aggregated land rent of livestock sectors is smaller than the aggregated land rents of agricultural crops. For example, in the U.S. observed average cropland cash rent is $70/acre and that of pastureland is only $9/acre, clearly indicating the marginality of pasture land. Similarly, Lee *et al.* (2009) compute the forest cover land rent by using information on timberland land rent and timberland area offered by Sohngen *et al.* (2009). Since inaccessible forests do not generate any commercial land rents, by definition, Lee *et al*. exclude the inaccessible forest area when computing the forest land rents. A comparison of per hectare land rents indicates that forest land rents are slightly smaller than that of aggregated pasture sector rents indicating their marginality – or perhaps the cost of access/developing the land.

Now returning to marginal lands, after obtaining data on their physical area, we compute per hectare land-rents (LR) for the new categories – CRP-lands and cropland-pasture as explained below. Campbell *et al*. (2008) estimate that the potential yield in abandoned or degraded farmlands across the globe, is equivalent to nearly half of the yield in regular cropland, depending on local soils, climate, and cultivation practice. In the same way, we assume that cropland-pasture is more productive than pasture-cover area (grassland) and less productive than the regular cropland. A share-weighted rent for each existing AEZ was extracted from *pasture-cover* and *food crops'* land rents.

$$LR_{ir}^{CP} = \begin{cases} 0 \quad \text{if} \quad LR_{ir}^{PL} < 0 \quad \text{else,} \\ \theta_{ir}^{PL}.LR_{ir}^{PL} + (1-\theta_{ir}^{PL}).\dfrac{\sum_{FC}^{n} LR_{ir}^{FC}}{n} \end{cases} \tag{1}$$

where i $\in$ AEZs, CP $\in$ cropland-pasture, PL $\in$ pastureland or pasture-cover, FC $\in$ food crops; r $\in$ USA, Brazil, θ_{ir}^{PL} is assumed to be 0.6 for the U.S. and 0.8 for Brazil. That is, the productivity in cropland-pasture in the U.S. is the weighted sum of 60% of pasture-cover productivity and 40% of cropland productivity. Similarly, the cropland-pasture in Brazil is assumed to be between 80% of pasture-cover productivity and only 20% of regular cropland productivity. This is because there is not much difference between the land rents for pasture cover and the cropland used for growing field crops in Brazil. However, cropland used for growing much lucrative sugarcane crop has higher rents.

Since irrigated crops such as sugarcane, vegetables, fruits etc. have higher land-rents, extracting rents from these categories of crops for CRP-land and cropland-pasture is unrealistic. In general the cropland allotted for cultivation of pasture-crops or set aside under CRP is relatively less productive (Sullivan *et al.*, 2004), we include only food crops (coarse grains, oilseeds, paddy-rice and wheat) for extracting the land rents for the marginal lands. Similar to land rents for cropland-pasture, rent for CRP-land was also calculated as given below.

$$LR_{ir}^{CRP} = \theta_{ir}^{CRP} \frac{\sum_{FC}^{n} LR_{ir}^{FC}}{n} \tag{2}$$

where i $\in$ AEZs; $j \in$ CRP land.; $r \in$ USA, θ_{ir}^{CRP} is assumed to be 0.70 in the U.S. indicating that CRP lands are 30% less productive than the regular croplands[5]. The per-hectare land rents are used to compute the total land rents in each AEZ for the new categories of cropland.

The aggregated land rent of cropland-pasture was subtracted from the pasture-cover rents (as cropland-pasture was part of pasture-cover in principle) and that of CRP-lands was subtracted from 'capital' endowment in the 'government services' sector in the U.S. This is because the government gives CRP rental payments to the participant farmers so that the loss incurred by idling the cropland is compensated. In the GTAP data base, we equate the total CRP payments made by the government to the reduction in its capital endowment in order to retain a balanced data base. A similar land conservation policy called as 'set-aside' program was being followed in the European Union, the European Commission dropped the 10% set-aside program to 0% starting 2008-09 crop year when the food prices soared in 2008 and hence EU set-aside land data is not included in this study[6].

The total land rental payments in the GTAP data base measured in million dollars, before and after incorporation of CRP lands and cropland-pasture in the U.S. are provided in Table A1. It is important to note that, although we have added these land categories to the physical area of land, we have retained the economic value of total land endowment except for the CRP land rents in the U.S. The per acre rental payment of land in each AEZ across uses in the U.S are provided in Table A2. The key point here is that our computed rental payments for CRP-lands and cropland-pasture are smaller than per acre rent for crops and larger than that of pasture-cover and forest, indicating that the productivity of these marginal lands is in the same range.

Since cropland-pasture is an input into livestock production, we need to work it into a revised production structure. In the GTAP-AEZ model, there is only one pasture input, and this is identified as the "land" input in the livestock sector. However, now we have two potential inputs into the sector: cropland pasture and pasture – each with a differing productivity.

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[5] Based on oral communication with Lubowski, R.

[6] The European Union has been practicing a voluntary set-aside program since 1992 which has kept about 10% of its cropland as idle. Unlike in the U.S. the acreage under set-aside varies based on the mandate set for each year. In 2007 about 9.4 million acres were set-aside in the EU. As the biofuel boom began, about 3.7 million acres was brought under cultivation of biofuel feedstock (Gallagher, 2008). To combat the soaring food prices and to meet the biofuel feedstock requirements, the European Commission abolished the set-aside program permanently in July 2008 (European Commission, 2008)

Therefore, we opt to treat cropland-pasture as an intermediate input for the livestock sector in the model in order to differentiate it from pasture. Furthermore, the competition of livestock sector for feed grains, oilseeds and by-products of biofuels (DDGS and oil-meal) is handled as an intermediate demand function in the GTAP model (Taheripour *et al*. 2010). As the biofuels production increase, there will be more supply of byproducts as well. With the increasing price of feed grains and oilseeds (due to demand from biofuels sectors), the livestock sector would substitute the low-cost by-products for expensive feed commodities up to a threshold level. On the contrary, as the demand for livestock sector rises, the demand for feed commodities also rises, leading to demand for additional land to produce the feed commodities. This indirect interaction of livestock sector with land is discussed in Section 2.5.

We treat the CRP land rent as the tax/subsidy incurred by the government services sector, as the government rents this land in practice and makes payments to land owners. The CRP contracts for 10 to 15 years are made based on competitive bidding process which includes an index of environmental indicators and the cost incurred (Lubowski *et al.* 2006). Unlike cropland-pasture, treated as an extensive margin land, the CRP land movements are tracked through rental payments. After including the data on newly created categories of marginal lands, we check the balancing conditions of the data base which include standard accounting relationships to ensure that the integrity of the data base has not been disturbed (Pearson, 1995).

2.4 Incorporating Marginal Land-use into Land Supply Function

After creating the two new categories of cropland, these are incorporated into the second tier of the land-supply function[7] (Figure 1). The land is distributed across alternative uses through a CET function (equations (3) through (5) given in linearized form – as percentage change) based on the response of relative rental rates. In the first tier of land-supply function, the ease of land allocation across the three cover types is determined by the elasticity of transformation, Ω_1 which takes -0.20 as estimated by Ahmed *et al.* (2008). The percentage change in the quantity of cropland $qo_{ir}^{cropland}$ is obtained from equation (3).

$$qo_{ir}^{cropland} = qo_{ir} + \Omega_1.(pm_{ir}^{land} - pm_{ir}^{cropland}) \qquad (3)$$

[7] The detailed layout on the interaction of the market price of AEZ_i and supply of the cropland is given in Birur (2010)

where i, $\in$ AEZs; pm_{ir}^{land} is the percentage change in market price of AEZ-land endowment *i* in region *r*. $pm_{ir}^{cropland}$ is the percentage change in market price of cropland and qo_{ir} is the percentage change in land output which is assumed as exogenous and fixed. The equation (4) distributes the percentage change in quantity of land ($qoes_{ijr}$) across non-crop uses (forestry and pasture covers) with the same transformation parameter Ω_1.

$$qoes_{ijr} = qo_{ir} + \Omega_1.(pm_{ir}^{land} - pm_{ijr}^{es}) \tag{4}$$

where i, $\in$ AEZs; j $\in$ non-crop covers. pm_{ijr}^{es} is the percentage change market price of AEZ-land endowment *i* used by all non-crop sectors *j* in region *r*. In the second tier, the quantity of cropland is distributed across seven categories of crops (five crop categories, cropland-pasture and a CRP option) as given by equation (5).

$$qoes_{ijr} = qo_{ir}^{cropland} + \Omega_2.(pm_{ir}^{cropland} - pm_{ijr}^{es}) \tag{5}$$

where i $\in$ AEZs; j $\in$ crops ; Ω_2 is the elasticity of transformation of land across crops, taken as -0.50 which is the maximum acreage response elasticity for corn across different regions in the United States (FAPRI, 2004). The absolute value of the CET parameter gives the upper bound on the land supply elasticity in response to land rents for this CET land supply function. The CET parameters Ω_1 and Ω_2 are non-positive and their absolute value increases in absolute terms as the degree of sluggishness diminishes , thereby forcing the rental rates across alternative uses to move more closely together (Hertel *et al.*, 2009). Addition of two new sources of cropland in the land-supply function is expected to reduce the pressure on forest and pasture covers. For instance, Fischer *et al*. (2008) report that nearly two thirds of sugarcane expansion since 2006 has come from cropland-pasture lands in Brazil. The market clearing condition for land which stipulates land supplied equals land demanded is given by the following equation.

$$qoes_{ijr} = qfe_{ijr} \tag{6}$$

where qfe_{ijr} is the percentage change demand for land AEZ *i* for use in sector *j* of region *r*.

For handling the CRP land in the U.S., we examine two policy alternatives: (a) when the USDA decides defend the total amount of land enrolled under CRP, we fix (*exogenize* in the closure) the percentage change in quantity ($qoes_{ijr}$) of CRP-land in the U.S. and allow the rental rate to adjust to ensure total CRP land is fixed (b) when the USDA does not adjust rental rates, instead allowing the release of land enrolled under CRP, we fix the real rental rate on CRP land:

$$realpm^{es}_{ijr} = pm^{es}_{ijr} - cpi_r \tag{7}$$

The equation (7) computes the percent change in real return to land, across all the uses. When the percent change in real returns to CRP land ($realpm^{es}_{ijr}$) is fixed, it implies that the rental rates paid by the government are fixed. As market returns to crops change in the model, a given parcel of land is reallocated depending on the crops' suitability within a given AEZ. When the real return on CRP land is fixed and if the government wants to defend the CRP enrollment, then the government should increase the *ad valorem* subsidy to the extent of the change in relative consumer price index in the new market equilibrium. When the real-return to CRP land falls compared to returns from growing crops, then it is expected that the CRP land shifts to the crop of highest return in a given AEZi.

2.5 Cropland-Pasture in the Production Structure

Since the cropland-pasture is consumed by the livestock, we allow for substitution of cropland-pasture with the land-composite in the value added nest of the production structure (Figure 4). In the value added land nest, the price of the sub-product 'land' and the demand for inputs in the land nest are determined by equations (8) and (9), respectively.

$$pf_{'land'jr} = \sum_k \Psi^{CSHPSTUR}_{kjr} .(pf_{kjr} - af_{kjr}) \tag{8}$$

$$qf_{ijr} = -af_{ijr} + qf_{'land'jr} - \sigma^{EPSTUR}_{jr} .(pf_{ijr} - af_{ijr} - pf_{'land'jr}) \tag{9}$$

where $i, k \in$ cropland-pasture, composite-land*;* j $\in$ all the producing sectors*;* $\Psi^{CSHPSTUR}_{kjr}$ gives the share of cropland-pasture and composite land in the livestock sector in region *r*; The af_{ijr} variable refers to technological change induced by use of factor *i* in sector *j* in region *r*.

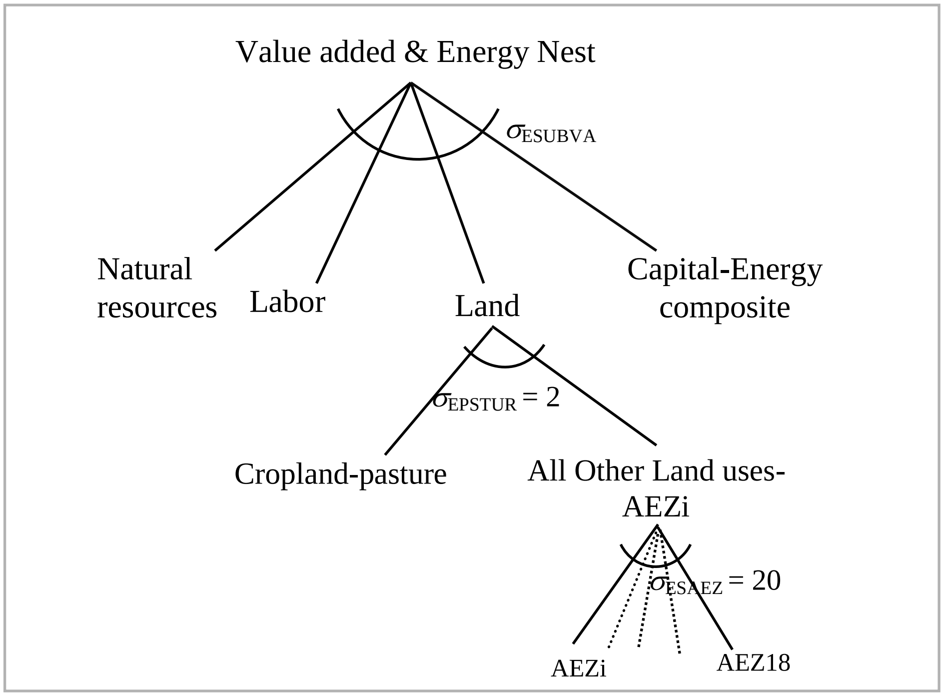


Figure 4. Cropland-Pasture Substitution in the Production Structure of the Model

The CES substitution elasticity (σ_{jr}^{EPSTUR}) defines the ease with which the cropland-pasture and land-composite substitute for one another in the livestock sector. We assume a value of 2 for this parameter[8].

3. Experimental Design

We consider two major biofuel policy scenarios: (1) to implement the U.S. and EU biofuel programs simultaneously for the year 2015, starting from the baseline 2006, and (2) to increase U.S. corn-ethanol production by 15 billion gallons per year in 2015, starting from 2001,

[8] For determining a reasonable value of σ_{jr}^{EPSTUR}, we have tried to calibrate based on econometric evidence on the U.S. land use transition offered by Lubowski (2002). Based on nationwide survey data on land-use at the plot level and county-level per acre profits in the U.S., Lubowski (2002) estimated land use transition across six different uses due to change in economic profits. As suggested by their study, a one percent increase in returns to crops would result in 0.044% increase in crop acreage with decline in pasture (-0.091%) and forest cover (0.007%) in the 5 year time period. The study further suggests that the same exercise would result in 0.115% rise in crop acreage compared to -0.197% and -0.024% change in pasture and forest covers, respectively. Though the study offers acreage elasticities for 100 years at 5 years of time interval, ideally we would be interested in the acreage response for 5 to 15 years for the biofuels policy analyses. Our model suggested that a one percent increment in crop returns would result in 0.121% rise in crop acreage with fall in pasture cover (-0.091%) and forest cover (-0.01%), when the value of this parameter is 2. Furthermore, the acreage response was quite insensitive to variation in the value of σ_{jr}^{EPSTUR}.

the base year of the data base. Both of these policies also integrated with two policies on CRP lands: (i) fixing the quantity of CRP land and (ii) fixing the real rents for CRP enrollment.

First we perform the baseline experiment as offered by Birur *et al*. (2008) to update the model over 2001-2006 period. The post-simulation data base forms the baseline for 2006. Following this 2006 baseline, in study, we have analyzed the first policy experiment mentioned above – the interaction of U.S. and EU biofuel mandates. In this study, we implement the first policy experiment analogous to Hertel *et al*. (2010a) experiment and distinguish the implications of incorporating marginal lands in the general equilibrium model. Our first policy experiment involves analyzing the impact of an increase in share of biofuels from 1.83% in 2006 to 5.09% in 2015 in the U.S., and that of EU from 1.23% to 6.25% (Table A3). The second policy experiment is exclusively corn-ethanol mandate in the U.S. which has recently drawn lot of attention due to its potential implications on indirect land use change. This experiment is implemented directly from 2001 base – an increase of 757% in volume of ethanol production from 1.75 billion gallons in 2001 to 15 billion gallons by 2015.

4. Results: Land Use and Land Cover Change

Since the purpose of this study is to examine the land-use implications due to marginal lands, we focus our discussion on land related variables from the general equilibrium model. Before we compare different policy scenarios, let us dwell on the 15 billion gallon U.S. corn-ethanol experiment without imposing any restrictions on CRP lands. This means, the government does not adjust the CRP land payments in response to market conditions and the land owner can move land in and out of CRP contract. The rationale to consider this case is, as we add new categories of marginal lands in the model, with no exogenous restrictions on a given type of land, the land in each AEZ adjusts across uses based on the changes in rents. Since this takes place at AEZ level, let us consider a case of AEZ-10 in the U.S. which basically covers the corn-belt area.

4.1 Interactions at AEZ Level

When production of corn-ethanol increases in the U.S., it demands more feedstock which in turn pushes the corn prices up, stimulating the acreage under corn-crop. As the demand for land goes up, the rental rates also rise depending on the suitability of land for growing the feedstock crop. As specified in equation (3), the quantity of cropland supplied is determined based on the difference between changes in total land price versus cropland price, guided by the transformation elasticity, Ω_1. Similarly based on the change in supply price of other land covers, the quantity of forest and pasture covers are also determined by equation (4). As seen from Table 2, the percentage changes in physical land of forest and pasture-cover are -0.44% and -0.54%, respectively. But when the crops are grown on the converted land from these two cover types, the average yields decrease (as indicated by the per acre rents) and hence the effective land decreases more than do the physical acres.

It is important to note that the land rents which measure the economic contribution of land and hence their productivity, vary widely across land cover types. The *ex post* result indicates that average land rent in the U.S. corn-belt is \$161/acre and that of forest and pasture covers is only \$10 and \$6 per acre, respectively (Table 2). If we consider part of this varied difference as an indicator of difference in productivity across cover types (the remaining difference may be attributed to conversion costs that are not accounted for), then we can envisage the decline in crop yield in the newly converted lands. In this study, following Hertel *et al*. (2010a) we adjust the model predicted productivity differences with a parameter called "ETA" which assumes based on professional judgment that the yields obtained in the newly converted land are about two-thirds (ETA=0.66) to that of yields obtained in regular cropland.

Table 2. An Illustration of Land-Cover adjustment in the U.S. Corn-belt (AEZ-10)

Experiment: U.S. Corn Ethanol mandate (with no restriction on CRP).				
Land cover type	Rents in AEZ-10 (US\$/acre)	*Percent change*		
		Effective land	Productivity adjustment	Physical land
Forest cover	10	-4.04	-3.60	-0.44 (-0.67 m. ac.)
Pasture cover	6	-4.14	-3.60	-0.54 (-0.15 m. ac.)
Cropland	161	0.42	-0.25	0.67 (+0.83 m. ac.)

Since the new cropland now includes additional converted land from the less productive forest and pasture covers, the effective land decreases by 4% each. However, the land which comes out of forest and pasture covers is the most productive within their cover type, and hence the productivity drops by 3.60%. As a result, the change in physical land is only -0.44% (-0.67 m. acres) and -0.54% (-0.15 m. ac) for forest and pasture covers, respectively. Though, the overall increase in physical area of cropland is 0.67% (0.83 m. acres), due to relatively less productive land coming in from the forest and pasture covers, the effective increase in cropland is only by 0.42%. In other words, in order to increase effective cropland area by 0.42%, we need to increase physical harvested area by 0.67%. Recall that the pasture-cover rents are computed based on coarse grain yield and that of forest cover is based on the value of timber production within a given AEZ. Therefore, it is important to note that the land rents do not include any access cost, involved in conversion across cover types. In lights of this point, the relative productivity across cover types as indicated by the land rents could be exaggerated.

To further understand the distribution of effective cropland, Table 3 offers decomposition of equations (3) and (5) by variables for AEZ-10 in the U.S. It is clear from the table that change in supply price of cropland, pm_{ijr}^{es} is much higher for coarse grains (mainly corn in the U.S.) compared to all other crops including CRP-land and cropland-pasture. With the exception of coarse grains, all other crop-categories show that $pm_{ijr}^{es} < pm_{ir}^{land} < pm_{ir}^{cropland}$. As a result, the additional land needed to grow corn in AEZ-10 is drawn out of all other crop-categories. The percent change in cropland, $qoes_{ijr}$ for coarse grain is 12.3% and that of CRP-land and cropland-pasture is -12.9% and -9.6%, respectively.

The land rents in AEZ-10 for the seven crop categories (Table 4) show that the irrigated crops such as sugar-crops (mostly sugar-beet in the U.S. corn-belt), other agricultural crops such as fruits and vegetables, showed higher rental rates compared to food grains and oilseeds. The CRP-land rent was $76 per acre and that of cropland-pasture was only $12 per acre. The percent change in land rent, lr_{ijr} indicates that due to corn-ethanol production, the change in land rent was highest for coarse grains (73%) compared to other crop categories.

Table 3. Distribution of Cropland in the U.S. Corn–belt (AEZ-10)

Experiment: U.S. Corn Ethanol mandate (with no restriction on CRP)							
Crop categories	% Ch in effective cropland	CET parameters		% Ch in market price of cropland	% Ch in market price of total land	% Ch in supply price of cropland	% Ch in cropland distributed
	$qo_{ir}^{cropland}$	Ω_1	Ω_2	$pm_{ir}^{cropland}$	pm_{ir}^{land}	pm_{ijr}^{es}	$qoes_{ijr}$
Coarse Grains	0.42	-0.2	-0.5	44.6	41.6	80.8	12.3
Oilseeds	0.42	-0.2	-0.5	44.6	41.6	22.8	-7.5
Sugar-crops	0.42	-0.2	-0.5	44.6	41.6	25.5	-6.5
Other Grains	0.42	-0.2	-0.5	44.6	41.6	13.6	-11.0
Other Agri	0.42	-0.2	-0.5	44.6	41.6	31.3	-4.3
CRP-land	0.42	-0.2	-0.5	44.6	41.6	8.8	-12.9
Cropland-pasture	0.42	-0.2	-0.5	44.6	41.6	14.7	-9.6

By using the price (pm_{ijr}^{es}) and quantity ($qoes_{ijr}$) information from Table 3, we compute the change in physical land area (ha_{ijr}) by dividing the new land revenue by rental rate (lr_{ijr}) as given in equation (10) in linearized form.

$$ha_{ijr} = pm_{ijr}^{es} + qoes_{ijr} - lr_{ijr} \tag{10}$$

Based on the physical land data for 2001, we compute the *ex post* physical acres of harvested area: $HA_{ijr}^{2015} = HA_{ijr}^{2001}.ha_{ijr}$ and the change in acres, $\overline{HA}_{ijr} = HA_{ijr}^{2015} - HA_{ijr}^{2001}$. As seen from Table 4, the model predicts an increase of 5.85 million acres of coarse grains area in AEZ-10 and much of this increment mainly comes from reduction in area under oilseeds, CRP-lands, and cropland-pasture. The central part of this study is to get the change in physical land-use and land-cover correct, as indirect land use emission is the major decisive factor in biofuel policy formulations. Therefore we devote the rest of the study in examining the land use changes due to various policy alternatives.

Table 4. Change in Physical Cropland Area in the U.S. Corn-belt (AEZ-10)

Experiment: U.S. Corn Ethanol mandate (with no restriction on CRP)					
Crop categories	2001 Rent ($/acre)	2015 Rent ($/acre)	% Change in rent, lr_{ijr}	% Ch in harvested area, ha_{ijr}	Ch in harvested area, $\overline{HA}_{ijr}$ (mill. acres)
Coarse Grains	120.5	212.0	76	15.5	5.85
Oilseeds	47.9	57.1	19	-4.9	-1.53
Sugar-crops	265.8	324.4	22	-3.8	-0.02
Other Grains	145.4	160.7	11	-8.5	-0.63
Other Agri	198.7	253.8	28	-1.6	-0.43
CRP-land	76.4	80.9	6	-10.5	-1.51
Cropland-pasture	12.4	14.1	14	-7.1	-0.90

4.2 Land Interaction in the Livestock Sector

In this section we illustrate the linkage established between cropland-pasture and land-composite in the livestock sector (as explained in Section 2.5). When there was no cropland-pasture in the model, consider the land supply represented as LS_1 in Figure 5. If there is a shift in land demand (LD_2) due to corn-ethanol production in the U.S., LD_2 intersects with LS_1 resulting in equilibrium price, P_1 and quantity, Q_2. For instance, as seen from Table 5, the 15 bgy corn-ethanol experiment results in -3.12% change in land demanded by the livestock sector as there is greater change in cropland rents. Decomposition of this result reveals that rise in land demand in the livestock sector has been mainly due to fall in price in the model with cropland-pasture. The interaction of price and quantities in the land market translate into change in land rents. In the U.S. corn-belt (AEZ-10), the change in cropland rent in the livestock sector is 53.17% and that of pasture land is 9.71%.

When we introduce cropland-pasture to readily substitute with other land uses in the livestock sector, the land supply curve becomes more elastic (LS_2). A shift in land demand, LD_2 due to biofuels production results in lesser change in cropland rent (P_2) and hence more change in cropland conversion (Q_3) from non-cropland uses. As seen from Table 5, the change in land demand from the livestock sector is -3.19% in the model with cropland-pasture and that of change in cropland-rent falls to 44.25%, but raises that of pasture land and cropland-pasture rents by 10.52% and 13.95%, respectively. Though there is greater conversion of cropland for use in the livestock sector, the net change in land conversion from other land covers would determine the intensity of GHGs emissions. This implies that corn-ethanol experiment would require lesser cropland in aggregate in the presence of cropland-pasture, which is further explored in Section 4.6.

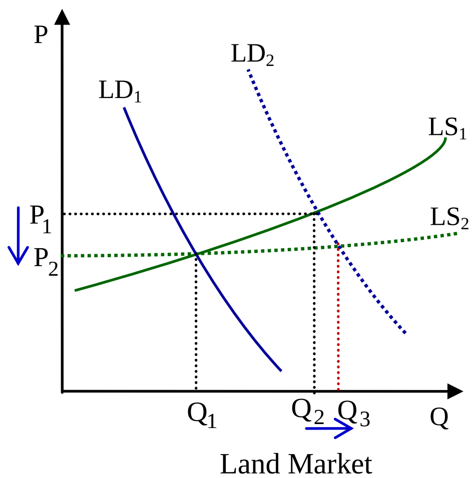


Figure 5. Graphical Illustration of Land Interaction in the Livestock Sector

Another factor that influences the elasticity of land supply in the livestock sector is our assumption on the value of the parameter, σ_{jr}^{EPSTUR}. To explore further the role of this parameter, consider the case in which we have taken its value as 2, which is comparable to the land supply, LS_1 in Figure 5. If the demand for land (LD_2) due to U.S. corn-ethanol production intersects with LS_1, it results in equilibrium price, P_1 and quantity, Q_2. If we decompose equation 9, the corn-ethanol experiment in the U.S. results in -3.714% change in price and -6.246% change in quantity of cropland-pasture while the change in quantity of land-composite is -2.291 (lower panel of Table 5).

Consider another case in which the value of σ_{jr}^{EPSTUR} is 10 offering more ease with which the cropland-pasture can substitute for other uses in the livestock sector, reflects a flatter land supply, LS_2. This means, the livestock sector can use as much land from cropland-pasture and land-composite as it requires compared to the case of LS_1. The market clearing condition which equates land supply and demand, results in equilibrium price, P_2 and quantity, Q_3.

Table 5. Decomposition of Land Substitution in the U.S. Livestock Sector.

Experiment: U.S. Corn Ethanol mandate (with no restriction on CRP)		
	Model with cropland-pasture	Model without cropland-pasture
Percent change in total land in the livestock sector in the U.S.:		
Quantity (qf)	-3.197	-3.116
Contribution from price change:	-2.550	-2.388
Contribution from demand change:	-0.896	-0.956
U.S. corn-belt (AEZ-10)	Model with cropland-pasture	Model without cropland-pasture
Percent change in *land rents* due to cropland-pasture linkage:		
Cropland-pasture rent	13.953	-
Cropland rent	44.255	53.174
Pasture land rent	10.526	9.714
	EPSTUR = 2	EPSTUR = 10
Percent change in *total land* in the livestock sector in the U.S.:		
Quantity (qf)	-3.197	-3.227
Contribution from price change:	-2.550	-2.583
Contribution from demand change:	-0.896	-0.899
Percent change in pasture and cropland-pasture in the livestock sector in the U.S.		
pf (land-composite)	1.069	1.222
pf (cropland-pasture)	-3.714	-4.259
qf (land-composite)	-2.291	-2.195
qf (cropland-pasture)	-6.246	-6.730

As indicated by the decomposed results from equation 9, the price of cropland-pasture falls more (-4.259%) with greater use of cropland-pasture (-6.730%) in the livestock compared to the case where the value of σ_{jr}^{EPSTUR} was 2. However, greater the ease of cropland-pasture conversion which in turn reduces the pasture conversion, also puts upward pressure on forest conversion due to the CET structure of the land supply which allows new cropland to come from forest and pasture covers.

4.3 Baseline Experiment

As discussed in the earlier section, the baseline experiment which includes the key biofuel drivers is essential to validate the model over the historical period 2001-2006 (Birur, Hertel, and Tyner, 2008). Here we present a comparative analysis of four different scenarios of the same baseline experiment. Table 5 presents the physical change in land use and land cover for: (i) model with no marginal lands, (ii) model with marginal lands – without any restriction on CRP acres[9], (iii) model with CRP-land fixed, and (iv) model with CRP-land released (fixed real rents to CRP).

As the key drivers induce biofuels production in the U.S., and EU, the economy demands more feedstock, which in turn puts expansionary pressure on cropland from other land covers such as commercial forest and pasture-cover. Due to intercrop substitution based on cropping suitability of land, it is expected that addition of two marginal land categories in the model would allow for greater degree of shift in cropping pattern within the cropland thereby offsetting the pressure on forest or pasture covers. As presented in Table 6, when there are no marginal lands in the model, the percent change in crop-cover is slightly larger (0.14% in U.S., 0.39% in EU, 1.34% in Brazil) compared to that of the model with marginal lands (case-ii: 0.11% in U.S., 0.37% in EU, 1.69% in Brazil). The most crucial result of this study, as expected, is the decline in forest degradation with the introduction of marginal lands in all the three regions.

The change in physical acres of land-cover and harvested area (in million acres) presented in the lower panel of Table 6 are the sum of all the existing AEZs' area in a given region: $\overline{HA}_{jr} = \sum_{i=1}^{18} \overline{HA}_{ijr}$. The land cover change computed in the similar way showed that when the marginal lands are not included, the pasture cover changed by -0.63, -0.21, +0.42 million acres, in the U.S., EU, and Brazil respectively, versus -0.93, -0.31, -0.17 million acres with the presence of additional marginal lands. This drastic reduction in degradation of pasture-cover is expected to reduce the carbon-emission resulting due to biofuel drivers. However, the forest cover showed greater decline when the marginal lands are included in the model relative to the model with no marginal lands. For instance, the increase in sugarcane acreage in Brazil is relatively much larger in the presence of marginal lands, which demands more deforestation. This is because, the cropland-pasture incorporated in the land nest has slightly higher productivity (land rents) than that of pasture-cover. Due to this difference cropland-pasture responds faster to market forces and readily substitutes for pasture-cover, thereby putting downward pressure on forest cover.

[9] In this case, no restriction on CRP land is imposed exogenously in the closure. As a result, CRP land category works just as other categories of crops. This case helps in clarifying comparison between the models with versus without these additional categories of marginal lands.

Let us consider only the model with marginal lands in Table 6 and examine the CRP land issues in the U.S. As noted earlier, although CRP land is treated as an additional possibility of land use in the model, in reality it is the prerogative of the USDA to fix the quantity of CRP enrollments or release any land for cultivation. Since the Farm Bill extends the CRP enrollment to 32 million acres until 2012, we consider a case of fixing the quantity of CRP land ($qoes_{ijr}$) and another case of fixing the real rents of the CRP land ($real\_pm_{ijr}^{es}$) implying that the USDA does not defend the CRP payments. As portrayed in Table 5, the baseline experiment shows that when CRP lands are fixed, there are significant shifts in cropping pattern compared to the case of when CRP is released. Interestingly, the release of CRP has a greater role in reducing the pressure on decline in forest and pasture covers. With CRP contracts fixed, there is lesser availability of cropland to allocate land across alternative uses. Due to this restriction on intensive margin, the market induced demand for land puts additional pressure on extensive margin and hence the forest cover goes up only by 0.06 million acres in the U.S., compared to 0.13 million acres of forest expansion when the CRP land is released for cultivation.

4.4 U.S. and EU Biofuel Mandates

The four cases after the baseline experiment discussed in the previous section form the 2006 baseline for implementing the U.S. and EU biofuel mandate experiment. Since this policy experiment involves exogenous increase of corn-ethanol and biodiesel in the U.S., and biodiesel in the EU for 2015, we expect greater demand for the respective feedstocks in the given regions. As reported in Table 7, with no explicit marginal lands available for use in the model, there was a strong cropping pattern shift towards the biofuel feedstocks but at a much larger reduction in other crops. For instance, the model predicts an increase of 7.1% coarse grain area and 4% oilseed area in the U.S., which required at least 8% reduction in other grains area. But in the presence of marginal lands without any restrictions on CRP, the model predicted an 7.3% increase in coarse grain area and 5.7% increase in oilseed area, but the reduction in other grains area was only 5% and much of the shift came from reduction in cropland-pasture area (-7%).

Interestingly, with the additional marginal lands in place, the reduction in forest cover was much larger in all the three regions (-1.3, -7.5, and -3.2 million acres in the U.S., EU, and Brazil) compared to that of model with no marginal lands (-0.31, -6.9, and -0.5 million acres, respectively). However, the reduction in pasture-cover in the U.S. was much larger in the U.S. compared to decline in forest cover. This is because the pasture-cover is more responsive than the other cover-types and hence much of the conversion results from pasture lands. Ahmed, Hertel and Lubowski (2008) report that pasture-cover is more responsive than forest-cover to increases in crop returns in the short-run. Even when the CRP land is fixed, the land cover results are about same as that of the case with no restrictions on CRP land. However, when the CRP land is released, the model predicts about 6.3 million acres of reduction in CRP land and only 2 million acres of reduction in other grains area. In fact the harvested area under other agricultural crops (vegetables, fruits, etc.) rises slightly in the U.S. when the CRP lands are available for cultivation.

Furthermore, Table 7 indicates that with the presence of additional marginal lands, the biofuel feedstocks acreage expand much faster without reduced much acreage under other crop categories. As expected, the CRP release case showed the least amount of forest and pasture cover decline relative to other two cases. Since this experiment involves implementing U.S. and EU biofuel policies, it is important to understand the land cover implications, particularly in Brazil, as it is a key player in supplying sugarcane based ethanol and soybean as biodiesel feedstock. Interestingly, due to import demand of ethanol-2, sugarcane acreage expands much faster compared to that of model with no marginal lands. This greater increase comes from large reductions in cropland-pasture area (4.6 million acres), but also at the cost of forest cover (3.2 million acres). When CRP land is released, the cropping pattern shift shows much lesser pressure on harvested area of competing food crops.

Table 6. Change in Land-Use and Land-Cover in the Baseline Experiment

2001-2006	*Model with No Marginal Lands*			*Model with Marginal Lands*			*Marginal Lands with fixed CRP*			*Marginal Lands with CRP released*		
	U.S.	EU	Brazil	U.S.	EU	Brazil	U.S.	EU	Brazil	U.S.	EU	Brazil
Land use change (%):												
Coarse Grains	2.36	-1.74	-0.30	2.63	-1.65	0.01	2.46	-1.64	0.02	2.64	-1.65	0.01
Oilseeds	0.55	12.57	0.29	1.02	12.86	0.37	0.81	12.89	0.41	1.03	12.86	0.37
Sugar-crops	-1.03	-0.58	18.07	-0.67	-0.51	30.01	-0.80	-0.51	30.01	-0.67	-0.51	30.01
Other Grains	-2.06	-1.29	-0.84	-1.25	-1.36	-0.84	-1.51	-1.36	-0.83	-1.24	-1.36	-0.84
Other Agri	-0.50	-0.43	-1.42	-0.41	-0.26	-1.03	-0.48	-0.26	-1.03	-0.41	-0.265	-1.03
CRP-Land				-1.86	-	-	0	-	-	-1.94	-	-
Cropland-pasture				-1.28	-2.07	-2.22	-1.48	-2.10	-2.24	-1.27	-2.06	-2.22
Land cover change (%)												
Crops	0.14	0.39	1.34	0.11	0.37	1.69	0.13	0.38	1.70	0.11	0.37	1.69
Forest	0.03	-0.26	-0.39	0.01	-0.28	-0.66	0.01	-0.28	-0.66	0.02	-0.28	-0.66
Pasture	-0.16	-0.20	-0.04	-0.12	-0.14	0.11	-0.13	-0.15	0.11	-0.12	-0.14	0.11
Land use change (million acres)												
Coarse Grains	2.12	-1.48	-0.09	2.36	-1.40	0.00	2.21	-1.39	0.01	2.37	-1.40	0.00
Oilseeds	0.44	4.00	0.10	0.82	4.09	0.13	0.65	4.10	0.15	0.83	4.09	0.13
Sugar-crops	-0.03	-0.04	2.24	-0.02	-0.03	3.73	-0.02	-0.031	3.73	-0.02	-0.031	3.73
Other Grains	-1.47	-0.82	-0.07	-0.74	-0.87	-0.09	-0.89	-0.86	-0.09	-0.73	-0.87	-0.09
Other Agri	-0.41	-0.42	-0.49	-0.39	-0.26	-0.32	-0.46	-0.26	-0.32	-0.39	-0.26	-0.32
CRP-Land				-0.74	-	-	0	-	-	-0.77	-	-
Cropland-pasture				-0.79	-0.34	-1.30	-0.92	-0.34	-1.31	-0.79	-0.34	-1.29
Land cover change (million acres)												
Crops	0.66	1.25	1.70	0.51	1.20	2.15	0.60	1.22	2.15	0.50	1.20	2.15
Forest	0.27	-0.93	-1.53	0.12	-1.00	-2.57	0.06	-1.01	-2.58	0.12	-0.99	-2.57
Pasture	-0.93	-0.31	-0.17	-0.63	-0.21	0.42	-0.66	-0.21	0.42	-0.62	-0.21	0.42
Pastures + CRP Combined	-0.93	-0.31	-0.17	-2.16	-0.54	-0.87	-1.58	-0.55	-0.89	-2.19	-0.54	-0.87

Table 7. Change in Land-Use and Land-Cover due to U.S. and EU Mandates

2006-2015	*Model with No Marginal Lands*			*Model with Marginal Lands*			*Marginal Lands with fixed CRP*			*Marginal Lands with CRP released*		
	U.S.	EU	Brazil	U.S.	EU	Brazil	U.S.	EU	Brazil	U.S.	EU	Brazil
Land use change (%):												
Coarse Grains	7.12	-3.85	-3.89	7.35	-3.43	-3.10	7.71	-3.44	-3.19	9.37	-3.58	-3.24
Oilseeds	4.01	53.00	16.03	5.68	55.95	14.42	5.92	56.10	14.96	7.87	56.13	14.66
Sugar-crops	-4.35	-0.86	5.18	-3.37	-0.49	45.05	-3.50	-0.28	45.49	-2.30	-0.24	45.64
Other Grains	-7.56	-9.28	-8.60	-5.12	-9.73	-12.71	-5.41	-9.72	-13.04	-3.35	-9.69	-13.04
Other Agri	-1.06	-0.64	-3.21	-0.82	0.39	-2.16	-0.88	0.63	-2.27	0.03	0.644	-2.24
CRP-Land				0.75	-	-	0	-	-	-16.12	-	-
Cropland-pasture				-7.19	-16.25	-8.14	-7.46	-16.33	-8.35	-5.98	-16.16	-8.22
Land cover change (%)												
Crops	0.77	2.89	2.67	0.77	2.84	3.63	0.80	2.85	3.67	0.69	2.84	3.65
Forest	-0.04	-1.92	-0.13	-0.15	-2.09	-0.82	-0.16	-2.11	-0.84	-0.11	-2.10	-0.84
Pasture	-0.56	-1.50	-0.65	-0.44	-1.12	-0.38	-0.45	-1.12	-0.38	-0.42	-1.11	-0.38
Land use change (million acres)												
Coarse Grains	6.55	-3.21	-1.16	6.78	-2.86	-0.93	7.09	-2.87	-0.95	8.63	-2.98	-0.97
Oilseeds	3.24	18.96	5.63	4.62	20.07	5.07	4.80	20.13	5.26	6.40	20.13	5.15
Sugar-crops	-0.11	-0.05	0.76	-0.08	-0.021	7.27	-0.09	-0.017	7.35	-0.06	-0.014	7.37
Other Grains	-5.30	-5.79	-0.71	-2.98	-6.09	-1.43	-3.14	-6.08	-1.47	-1.95	-6.07	-1.47
Other Agri	-0.86	-0.63	-1.08	-0.77	0.54	-0.67	-0.82	0.61	-0.70	0.03	0.63	-0.69
CRP-Land				0.29	-	-	0	-	-	-6.29	-	-
Cropland-pasture				-4.39	-2.58	-4.64	-4.54	-2.60	-4.75	-3.65	-2.57	-4.68
Land cover change (million acres)												
Crops	3.52	9.28	3.44	3.49	9.13	4.68	3.61	9.17	4.73	3.12	9.13	4.71
Forest	-0.31	-6.92	-0.52	-1.26	-7.53	-3.19	-1.31	-7.58	-3.25	-0.96	-7.56	-3.23
Pasture	-3.21	-2.36	-2.92	-2.24	-1.59	-1.49	-2.31	-1.59	-1.48	-2.16	-1.57	-1.48
Pastures + CRP Combined	-3.21	-2.36	-2.92	-6.33	-4.18	-6.13	-6.85	-4.19	-6.24	-12.09	-4.14	-6.16

4.5 U.S. Corn Ethanol Only Mandate

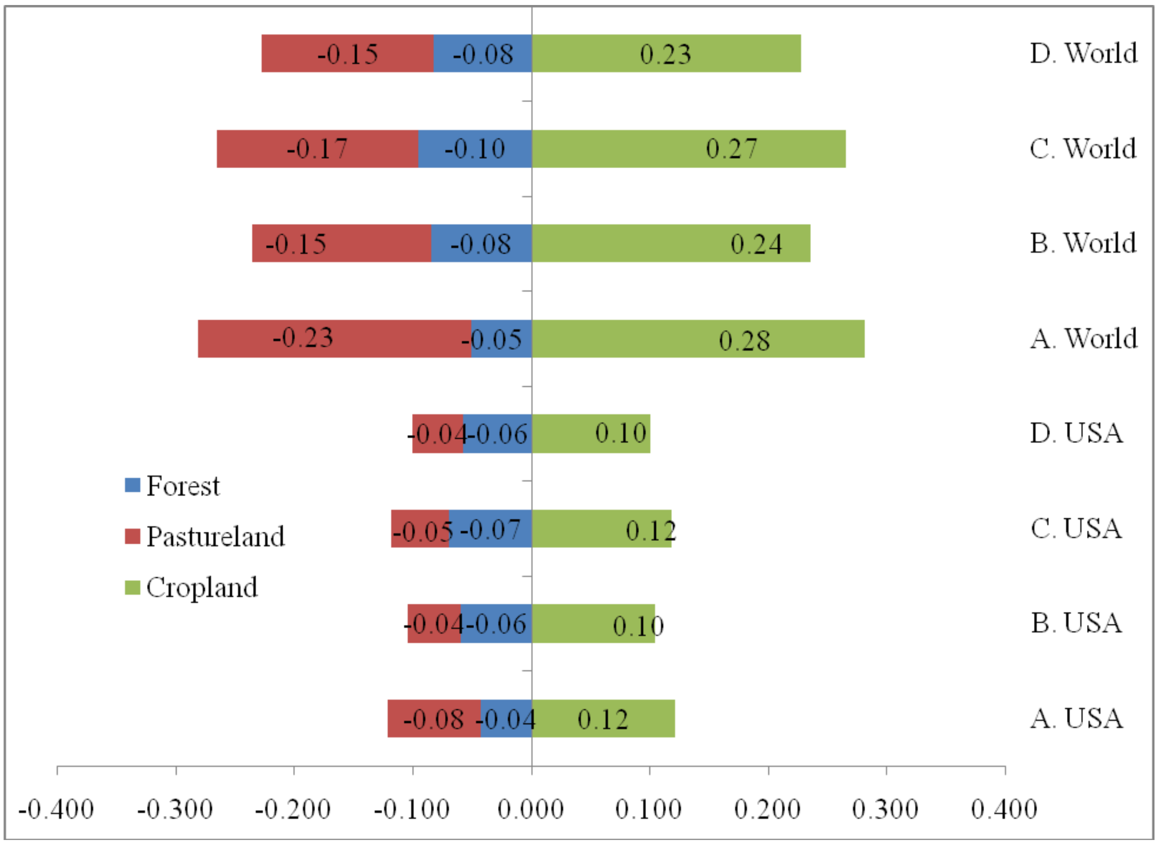
As discussed earlier, in this experiment we examine the implications of an increase in corn ethanol to 15 billion gallons by 2015. As evident from Table 8, when the marginal land categories are not included, the model prediction is that acreage under coarse grains in the U.S. increases by more than 15% (14 million acres) which comes mainly at the expense of decline in area under all other crops - particularly the oilseeds area by 5% (-4 million acres) and that of other grains (paddy rice and wheat) by 9% (-6 million acres). Furthermore, the cropland cover expands by 0.8% (3.6 million acres) in the U.S., which comes at the cost of 1.2 million acres of forest cover and 2.3 million acres of pasture-cover. As the U.S. agricultural supply and demand flux due to ethanol mandate imparts to rest of the world through trade linkages, the cropland in Brazil expands only by 0.6 million acres, much of which is devoted to grow much demanded coarse grain (corn) and the U.S. displaced oilseeds (soybean). This cropping shift occurs with the forest loss of 0.1 million acres and conversion of pasture-cover into cropland of 0.5 million acres. In the presence of marginal lands, without imposing any restrictions on CRP lands, the U.S. corn-ethanol policy has much lesser impact on land-covers in the EU. Whereas, though pasture-cover reduction is much smaller in Brazil, astonishingly forest cover declines much more in the model with additional marginal lands.

Furthermore, when we fix the quantity of CRP land, with the cropland-pasture area in place to substitute for, the coarse grains area increases by 16% (14 million acres), but there is greater reduction in oilseed and other grains area is by 5% (3.9 million acres) and 7% (4.2 million acres), respectively in the U.S. However, this reduction in oilseed area has been picked up partially by EU and Brazil. The major portion of cropping pattern shift in the U.S. comes from the less productive cropland-pasture area (5%, 3.4 million acres). Consequently, the U.S. cropland expands by 3.5 million acres with forest and pasture cover degradation of 2 and 1.4 million acres, respectively. When the CRP land is released, the cropping pattern adjusts such that the CRP land and cropland-pasture area gives in by 11.5% (4.6 million acres) and 4% (2.6 million acres), respectively in the U.S. As expected, when the CRP land is released, the land cover impact is slightly smaller than that of other cases.

Table 8. Change in Land-Use and Land-Cover due to U.S. Corn-Ethanol Mandate

2001-2015	*Model with No Marginal Lands*			*Model with Marginal Lands*			*Marginal Lands with fixed CRP*			*Marginal Lands with CRP released*		
	U.S.	EU-27	Brazil	U.S.	EU-27	Brazil	U.S.	EU-27	Brazil	U.S.	EU-27	Brazil
Land use change (%):												
Coarse Grains	15.57	0.28	1.20	16.95	0.32	1.52	15.86	0.34	1.62	17.25	0.32	1.50
Oilseeds	-4.93	1.23	1.39	-3.80	1.11	1.57	-4.91	1.28	1.81	-3.50	1.07	1.51
Sugar-crops	-2.87	-0.07	-0.95	-1.45	-0.02	-0.51	-2.18	-0.02	-0.51	-1.22	-0.02	-0.51
Other Grains	-8.65	0.18	-0.09	-5.77	0.18	-0.02	-7.14	0.21	0.00	-5.38	0.17	-0.02
Other Agri	-0.22	0.09	-0.44	0.52	0.15	0.07	0.02	0.17	0.10	0.69	0.139	0.07
CRP-Land				-8.55	-	-	0	-	-	-11.6	-	-
Cropland-pasture				-4.44	-1.19	-0.98	-5.49	-1.35	-1.10	-4.15	-1.15	-0.95
Land cover change (%)												
Crops	0.79	0.26	0.45	0.68	0.21	0.31	0.77	0.24	0.35	0.65	0.21	0.30
Forest	-0.15	-0.15	-0.03	-0.21	-0.14	-0.08	-0.24	-0.15	-0.09	-0.20	-0.13	-0.08
Pasture	-0.41	-0.19	-0.10	-0.26	-0.13	-0.02	-0.28	-0.15	-0.02	-0.25	-0.13	-0.02
Land use change (million acres)												
Coarse Grains	13.98	0.24	0.36	15.22	0.27	0.46	14.24	0.29	0.48	15.49	0.27	0.45
Oilseeds	-3.97	0.39	0.49	-3.06	0.35	0.55	-3.95	0.41	0.63	-2.82	0.34	0.53
Sugar-crops	-0.07	0.00	-0.12	-0.04	0.00	-0.06	-0.05	-0.001	-0.06	-0.03	-0.001	-0.06
Other Grains	-6.19	0.12	-0.01	-3.41	0.11	0.00	-4.21	0.13	0.00	-3.17	0.11	0.00
Other Agri	-0.18	0.09	-0.15	0.50	0.14	0.02	0.02	0.17	0.03	0.66	0.14	0.02
CRP-Land				-3.40	-	-	0	-	-	-4.60	-	-
Cropland-pasture				-2.75	-0.19	-0.57	-3.39	-0.22	-0.64	-2.56	-0.19	-0.56
Land cover change (million acres)												
Crops	3.57	0.83	0.57	3.07	0.69	0.39	3.49	0.77	0.44	2.97	0.67	0.38
Forest	-1.24	-0.54	-0.11	-1.77	-0.49	-0.31	-2.04	-0.55	-0.35	-1.70	-0.48	-0.30
Pasture	-2.32	-0.29	-0.46	-1.30	-0.19	-0.08	-1.45	-0.22	-0.10	-1.27	-0.18	-0.08
Pastures + CRP Combined	-2.32	-0.29	-0.46	-7.45	-0.38	-0.66	-4.84	-0.44	-0.74	-8.43	-0.37	-0.64

The land use results discussed above are normalized in terms of requirement to produce 1000 gallons of corn ethanol and the results are depicted in Figure 6, with different policy alternatives. When there are no marginal lands in the model, the model prediction is that 0.28 hectares of cropland is required globally to produce 1000 gallons of ethanol[10]. With the inclusion of marginal lands and allowing CRP land and cropland-pasture areas to substitute freely, the cropland requirement drops down to 0.24 hectares per 1000 gallons.



Note: **A:** Model with No Marginal Lands **B:** Model with Marginal Lands
C: Model with Marginal Lands - CRP fixed **D:** Model with Marginal Lands - CRP released

Figure 6. Land Cover Impact of U.S. Corn-Ethanol Production (Ha/1000 gallons)

If the USDA chooses to fix the CRP enrollment until 2015, the global cropland requirement goes up to 0.27 hectares (Figure 6). If the CRP land is officially released for cultivation, the requirement of global cropland eases to only 0.23 hectares per thousand gallons

[10] The land cover estimates and the resulting CO_{2E} estimations from this study are much higher than Hertel *et al.* (2010b) and CARB (2009) studies. This is because, Hertel *et al.* assume that the converted land from pasture and forest covers is two-thirds as productive as regular cropland as opposed to the model predicted productivity in this study. Since a one percent rise in harvested area does not require an equal amount of rise in land cover, those authors pre-multiply the land cover change by the ratio of harvested area to the land-cover.

of ethanol. The cropland requirement as decomposed into contribution of forest and pasture covers indicates that any reduction in cropland requirement comes mainly from lesser degradation of pasture-cover at the global scale.

4.6 Decomposition of Land Supply Response

As noted from the results above, though availability of cropland-pasture and CRP lands in the model has reduced impact on cropland expansion, the pasture-cover turns out to be much more responsive in the biofuel production scenarios. To understand these results, let us consider the land supply equation (4) discussed earlier.

$$qoes_{ijr} = qo_{ir} + \Omega_1.(pm_{ir}^{land} - pm_{ijr}^{es})$$

Where, pm_{ir}^{land} is the percentage change in market price of AEZ-land endowment *i* in region *r*, computed as the sum of land revenue share weighted change in price of land across the three cover types (Birur, Hertel, and Tyner, 2008).

$$pm_{ir}^{land} = \sum_k \Psi_{ikr}^{LC}.pm_{ikr}^{es}$$

By substituting for pm_{ir}^{land} in (4), we get:

$$qoes_{ijr} = qo_{ir} + \Omega_1.(\sum_k \Psi_{ikr}^{LC}.pm_{ikr}^{es} - pm_{ijr}^{es}) \qquad (11)$$

Since the total land endowment is exogenous and fixed ($qo_{ir} = 0$) and $pm_{ijr}^{es} \neq pm_{ikr}^{es} = 0$, equation (11) becomes,

$$\frac{qoes_{ijr}}{pm_{ikr}^{es}} = \Omega_1.(\Psi_{ikr}^{LC} - 1) \qquad (12)$$

The left hand side of the above equation indicates the change in quantity of land with respect to its own price, represented as the elasticity of land supply (η_j^{LC}) in a given region.

$$\eta_j^{LC} = \Omega_1.(\Psi_{ij}^{LC} - 1) \qquad (13)$$

If the land revenue share, $\Psi_{ij}^{LC} = \dfrac{PMES_{ij} * QOES_{ij}}{\sum_{k} PMES_{ik} * QOES_{ik}} \to 0$ in a given land using sector, then, $\eta_j^{LC} \to \Omega_1$. In this study, for example in the U.S., we have *added* CRP land and *transferred* a portion of pasture-cover as cropland-pasture, into the cropland sector. So the revenue share (Ψ_{ij}^{LC}) of cropland has increased simultaneously decreasing the share of pasture-cover and forest-cover. Since the elasticity of transformation (Ω_1) is constant, an increase in Ψ_{ij}^{LC} reduces the land supply response, η_j^{LC}. The land revenue shares and supply response for all the scenarios that we have examined in the study are reported in Table 9. As seen from the table, before incorporating additional marginal lands in to the model the land revenue share of cropland in the U.S., was 0.789 and it has increased to 0.829 after incorporating additional categories of marginal lands. At the same time, we can also notice the decline in land revenue of share of pasture-cover, from 0.103 to 0.067. The impact of this change in land revenue share is evident in the supply response – the cropland supply response has reduced and that of pasture-cover has increased slightly. If we revisit the land cover change results reported in Tables 6 - 8, after the new marginal lands are explicitly available in the model, the change in cropland cover has relatively declined, with much reduction in pasture cover change. Interestingly, this has resulted in further change in forest cover. The land revenue shares and supply response provided in the table for all the experimental scenarios facilitate in better understanding the dynamics of land cover results discussed in the previous sections.

In the second stage of land supply structure, from equation (5) we can derive the cropland supply response, η_j^{LU} with respect to change in land use revenue shares (Ψ_{ij}^{LU}) as follows.

$$\eta_j^{LU} = \Omega_2.(\Psi_{ij}^{LU} - 1) \qquad (14)$$

After allowing for cropland-pasture and CRP lands to substitute in the land use nest, the revenue share of all other land uses (Ψ_{ij}^{LU}) fall as the share of the new marginal lands increase (Table A4). Since Ω_2 is constant (= -0.50), as the revenue shares fall, the land supply response increases in crop sectors resulting in robust shift in cropping pattern as observed in Tables 6 – 8.

Table 9. Change in Land Cover Supply Response and Land Revenue Shares in the U.S.

Illustration: **U.S.**		**Land Revenue Share**			**Land Supply Response**		
	Model Version	Cropland	Pasture	Forest	Cropland	Pasture	Forest
2001 base data							
Pre-sim	With No Marginal Lands	0.7895	0.1027	0.1078	0.0421	0.1795	0.1784
Pre-sim	With Marginal Lands	0.8298	0.0671	0.1031	0.0340	0.1866	0.1794
Experiment: 15 bgy corn ethanol increment in the US from 2001 base							
Post-sim	With No Marginal Lands	0.8306	0.0814	0.0880	0.0339	0.1837	0.1824
Post-sim	With Marginal Lands	0.8580	0.0559	0.0861	0.0284	0.1888	0.1828
Post-sim	Marginal Lands with fixed CRP	0.8615	0.0546	0.0839	0.0277	0.1891	0.1832
Post-sim	Marginal Lands with CRP released	0.8572	0.0562	0.0866	0.0286	0.1888	0.1827
Experiment: Baseline experiment (2001-2006)							
Post-sim	With No Marginal Lands	0.7970	0.0978	0.1052	0.0406	0.1804	0.1790
Post-sim	With Marginal Lands	0.8344	0.0646	0.1010	0.0331	0.1871	0.1798
Post-sim	Marginal Lands with fixed CRP	0.8352	0.0643	0.1005	0.0330	0.1871	0.1799
Post-sim	Marginal Lands with CRP released	0.8344	0.0646	0.1010	0.0331	0.1871	0.1798
Experiment: US & EU 2015 Mandate experiment (2006-2015)							
Post-sim	With No Marginal Lands	0.8368	0.0760	0.0871	0.0326	0.1848	0.1826
Post-sim	With Marginal Lands	0.8650	0.0515	0.0835	0.0270	0.1897	0.1833
Post-sim	Marginal Lands with fixed CRP	0.8671	0.0507	0.0822	0.0266	0.1899	0.1836
Post-sim	Marginal Lands with CRP released	0.8622	0.0525	0.0853	0.0276	0.1895	0.1829

Note: "Pre-sim" and "Post–sim" indicate the results before and after the simulation experiments, respectively.

Since the revenue share of land under other agriculture is the highest in the U.S., followed by the Coarse Grains, these crop sectors showed greater degree of change in the harvested area in the presence of cropland-pasture and CRP-lands. The land supply response of cropland-pasture and CRP lands is relatively high compared to other crop sectors indicating the ease of substitutability with response of biofuel production shocks.

4.7 Sensitivity of Land Supply Response

As noted from the results on land use and land cover change due to biofuels production (Tables 6 - 8), interestingly forest cover responds more after incorporating cropland-pasture and CRP-lands. In order to investigate further, we changed the land transformation elasticities as -0.20 in both the tiers of the land supply structure. This implies a case where all the land using sectors including the land cover types compete together in a given AEZ. When the 15 billion gallon corn-ethanol production experiment (with no restriction on CRP lands) is implemented, in the absence of marginal lands, the forest cover change was -0.13% in the U.S., -0.15% in the EU, and -0.02 in Brazil (Table 10). When the marginal lands were available, the changes in forest and pasture cover were almost the same as that of the model with no marginal lands. This implies that the land transformation parameters significantly influence the pattern of land use and land cover change Apart from testing the parameters, we also tested if the data modification on cropland-pasture rents would influence results[11].

Table 10. Sensitivity of Land Supply Parameters on Land Use Change

	Experiment: U.S. Corn-Ethanol Production (2001-2015)					
	Model with No Marginal Lands			*Model with Marginal Lands*		
	U.S.	EU-27	Brazil	U.S.	EU-27	Brazil
Land use change (%):						
Coarse Grains	10.56	0.62	1.70	11.23	0.63	1.90
Oilseeds	-2.95	0.68	0.62	-2.42	0.65	0.76
Sugar-crops	-2.08	-0.05	-0.77	-1.36	-0.03	-0.53
Other Grains	-4.24	-0.01	-0.22	-2.87	-0.02	-0.26
Other Agri	-0.24	0.07	-0.36	0.09	0.10	-0.05
CRP-Land				-4.05	-	-
Cropland-pasture				-2.07	-0.49	-0.53
Land cover change (%):						
Crops	0.84	0.25	0.38	0.79	0.23	0.32
Forest	-0.13	-0.15	-0.02	-0.14	-0.14	-0.02
Pasture	-0.48	-0.17	-0.09	-0.48	-0.17	-0.08

[11] When we incorporated cropland-pasture rents in the data base, we deducted the computed cropland-pasture rents from the pasture-cover rents in each region, thereby ensuring that the data base is balanced. When we relaxed this modification and did not deduct the cropland-pasture rents from the pasture-cover rents implying that former is an addition to the data base, the corn-ethanol experiment revealed significantly larger change in forest cover when the value of land transformation parameters were -0.2 and -0.5 in the first and second tiers, respectively. This indicates that it is the land transformation parameters that drive the key results and the treatment of pasture rents.

5. Results: Implications on Land Use Emissions

One of the major driving forces for the popularity of biofuels use is their potential for GHGs savings. It has been argued that biofuels will reduce CO_2 emissions to fossil fuels and also growing feedstocks could be a CO_2 sink. As Searchinger *et al*. (2008) explain, when forest or pasture cover is converted to cropland for growing biofuel feedstock crops, loss of carbon occurs due to removal of vegetation, burning of trees, and soil carbon loss can occur due to plowing up the soil. As the standing vegetation sequesters carbon, it may be a net loss of carbon sequestered if growing forest is replaced by field crops. In the case of marginal lands, if the cropland is idled under CRP or being used to grow long-term pasture crops, the vegetation on these marginal lands sequesters carbon from the atmosphere into the soils. If this land is undisturbed for several years (CRP is enrolled typically for at least ten years), the accumulated carbon in the soils enhances the productivity of these marginal lands (Sullivan *et al*. 2004).

Typically the impact of biofuels on global GHG emissions has largely been explored using Life Cycle Analysis (LCA) – a form of engineering analysis with limited economic content. Hill *et al*. (2006) use LCA and find that the corn-ethanol yields 25% more energy and reduces 12% of GHGs, and soybean-biodiesel yields 93% more energy and reduces 41% of GHGs relative to fossil fuels. As Dufey (2007) reports, the reduction in CO_2 emissions vary by the type of feedstock – wood biofuel being extremely promising to the lowest from corn-ethanol. However, recently, results from economic models have been combined with LCA in order to permit assessment of more complex aspects of the problem, including international land use change. For instance, studies by Fargione *et al*. (2008) and Searchinger *et al*. (2008) indicate that U.S. corn-ethanol is a net emitter of GHGs when *indirect* land-use emissions are included.

When accounting for land use emission, the *direct* and *indirect* changes are the commonly used terms. The *direct* land use change refers to change induced by specific biofuel activity in a given region and the repercussions of a region's biofuel activity in another region is referred as *indirect* land use change (Kim *et al*., 2009). Recently, the indirect land use change (ILUC) has raised serious concerns among the biofuel policy makers as the magnitude of ILUC determines if a particular type of biofuel is net GHG emitter or not. In this study we estimate the ILUC emissions based on the land cover change results discussed in the previous sections. For this purpose we utilize the carbon emission factors measured as Mega grams of CO_2 equivalent

(CO_{2e}) per hectare for a period of 30 years (Table 11) adopted by CARB (2009) and Hertel *et al*. (2010b). These emission factors are computed following Searchinger *et al*. (2008) based on the global carbon flux data on oxidation and recovery of carbon in vegetation, soils, and forest products provided by Houghton and Hackler (2001). Though these carbon factors pertain to forest and pasture cover conversion, we consider that conversion of idled or marginal croplands also emit carbon in the same way as that of pasture-cover since most of the croplands grow grasses when they are kept idle.

Several studies have estimated the carbon flux in the marginal lands such as CRP land in the U.S. Brenner *et al*. (2001) reports that if the CRP land is converted to grasslands, it sequesters about 6.78 Mg of CO_{2e} per hectare per year in Iowa soils and that of Nebraska is only 2.64 Mg of CO_{2e}/ha/year (Brenner *et al.,* 2002). The Chicago Climate Exchange has set a protocol on carbon sequestration rate on CRP lands at 2.47 Mg CO_{2e}/ha/year (CCX, 2007). Fargione *et al.* (2008) report that when the abandoned lands such as CRP are converted to grow corn, net emissions are about 69 Mg of CO_{2e}/ha. Given this wide range of carbon factors, we settle for using the pasture-cover carbon factors adopted by CARB (2009) and Hertel *et al*. (2010b) for CRP as well as cropland-pasture (Table 11).

Carbon emissions from land cover change are computed by multiplying the carbon factors from Table 11 with the change in physical hectares of forest, pasture-cover, CRP land, and cropland-pasture, presented in Section 4 (Tables 6 through 8, for all the regions in the world). Table 12 reports land use emissions from implementing the U.S. and EU combined biofuel mandate, when there no marginal lands and when the quantity of CRP land is fixed (which is the current realistic scenario). With the combined mandate of the two regions, the total world-wide emissions were about 3.96 billion Metric tons of CO_2equivalent, of which, the total emission from EU alone is about 1.18 billion Metric tons of CO_{2E}, followed by Canada (856 mt), U.S. (696 mt), and Brazil (691 mt), when the additional marginal lands are present in the model (second panel of Table 12). Clearly, most of this total emission came from forest cover change (2 billion tons of CO_{2E}, globally) followed by 1 billion tons from pasture cover change and 0.86 billion tons from change in cropland-pasture. However, in the absence of explicit cropland- pasture sector in the model, the total global emissions from the U.S. and EU biofuel mandates was 2.14 billion tons of CO_{2E}, of which more than 1.23 billion tons are from pasture cover change and the remainder from forest cover change.

Table 11. CO_2e Emission Factors by Land Cover type (Mg CO_2e per hectare)

Regions	Forest-lost	Forest-gained	Pasture cover lost	CRP-lost	Cropland-pasture lost
U.S.A.	759.5	219.4	106.3	106.3	106.3
Canada	705.3	433.7	196.4		196.4
EU-27	297.4	362.0	155.6		155.6
Brazil	388.3	164.5	71.5		71.5
Japan	573.7	223.5	85.4		85.4
China-Hong Kong	573.7	223.5	196.4		196.4
India	573.7	223.5	196.4		196.4
Latin American Energy Exporters	388.3	164.5	71.5		71.5
Rest of Latin America & Caribbean	388.3	164.5	71.5		71.5
Eastern Europe & FSU Energy Exp	311.0	392.1	155.6		155.6
Rest of Europe	297.4	362.0	155.6		155.6
Middle Eastern N Africa energy exporters	152.4	58.7	82.4		82.4
Sub Saharan Energy exporters	305.1	129.3	42.5		42.5
Rest of North Africa & SSA	305.1	129.3	42.5		42.5
South Asian Energy exporters	936.6	337.0	85.4		85.4
Rest of High Income Asia	573.7	223.5	85.4		85.4
Rest of Southeast & South Asia	936.6	337.0	85.4		85.4
Oceania countries	388.2	197.8	97.9		97.9

Source: The carbon emission factors are adapted from CARB (2009) and Hertel *et al.* (2010b) studies, which are computed in line with Searchinger *et al*. (2008), based on the carbon flux data from Houghton and Hackler (2001).

Although addition of cropland-pasture has resulted in relatively lesser conversion of pasture and hence the emissions, but the forest cover emissions have increased (Table 12). This could be due to the reason that when the cropland-pasture is taken away from livestock grazing, the pressure from the displaced livestock sector would lead to increased forest clearing. The forest cover emission from EU-27, Canada, Brazil, and the U.S. are much higher compared to other regions, mainly due to import of oilseeds by EU-27 for its biodiesel production, which has resulted in significant land-use emissions. Due to this large magnitude of this indirect land use emissions, policy makers still debate whether it is appropriate to include these emissions when assessing the carbon intensity of biofuels. Since the mandate experiment involved exogenous fixing of CRP land in the U.S., there is no change in emissions resulting from conversion of CRP land. However, there are some offsets in emissions due to forest cover expansion in China, Eastern Europe and Russian regions.

Table 12. Land-Use Emissions due to U.S. and EU Biofuel Mandates (2006-2015)

Regions	**Model with No Marginal Lands**			**Model with Marginal Lands** (CRP land fixed in the U.S.)			
	Emissions (Million Metric Tons of CO_2 Equivalent)						
	Forest-cover	Pasture-cover	**Total Emission**	Forest-cover	Pasture-cover	Cropland-Pasture	**Total Emission**
U.S.A.	95	138	233	402	99	196	696
Canada	631	83	714	733	82	41	856
EU-27	833	149	981	913	100	164	1,176
Brazil	82	84	166	510	43	138	691
Japan	7	0	7	8	0	0	8
China-HK	-114	110	-4	-119	120	25	27
India	47	14	61	56	15	1	71
LAEEx	-15	35	20	20	26	35	81
RoLAC	-94	53	-41	-78	45	14	-19
EE & FSUEx	-507	357	-150	-386	304	208	126
RoE	9	51	59	16	44	22	82
MEAST & NAEx	0	14	14	0	16	4	20
SSA_Ex	-23	91	69	-14	101	11	98
RoAFR	-1	13	12	1	14	4	19
SASIA-Ex	-38	4	-34	-39	4	0	-35
RoHIA	0	0	0	0	0	0	0
RoASIA	-3	5	2	-2	5	1	4
Oceania	-2	31	28	-1	33	3	35
World	**907**	**1232**	**2139**	**2,017**	**1,053**	**866**	**3,936**

The land use emissions from the U.S. corn ethanol experiment are presented in Table 13. As seen from the first panel of the table, when there are no marginal lands, production of 15 billion gallons of corn ethanol in the U.S., results in total global emissions of 794 million metric tons of CO_{2E} from land conversion, two-thirds of which came from the U.S. alone. The only other region which contributed significantly to the total emissions was Canada. The forest cover change contributed 506 million tons towards global total emissions, while the pasture cover emissions were 288 million tons.

However, as seen from the second panel of Table 13, when cropland-pasture was available in the model, the total global emissions from corn-ethanol production were 1.28 billion tons, of which interestingly the forest cover sourced emissions were 829 million tons, and that of pasture cover and cropland-pasture were 213 and 240 million tons, respectively. Due to the linkage between cropland-pasture and pasture-cover that we established in the livestock sector, as expected the ethanol production experiment resulted in slightly smaller emissions from the pasture cover change. However, it is important to note that we used the same carbon intensity factors for cropland-pasture as that of pasture cover. Most of the increase in forest cover emissions came from the U.S. alone and impact on rest of the world was relatively much smaller as the feedstock demand for ethanol production in the U.S. is met from its domestic production.

Table 13. Land-Use Emissions due to U.S. Corn Ethanol Production (2001-2015)

Regions	**Model with No Marginal Lands**			**Model with Marginal Lands** (CRP land fixed in the U.S.)			
	Emissions (Million Metric Tons of CO_2 Equivalent)						
	Forest-cover	Pasture-cover	**Total Emission**	Forest-cover	Pasture-cover	Cropland-Pasture	**Total Emission**
U.S.A.	382	100	482	627	62	146	835
Canada	159	24	183	164	21	10	195
EU-27	65	19	83	67	14	14	94
Brazil	17	13	31	54	3	19	76
Japan	3	0	3	3	0	0	3
China-HK	-16	17	2	-15	17	5	7
India	5	2	7	5	2	0	7
LAEEx	0	10	10	18	6	12	35
RoLAC	-11	8	-3	-7	6	4	2
EE & FSUEx	-94	54	-40	-82	44	23	-15
RoE	4	6	10	4	5	3	12
MEAST & NAEx	0	5	5	0	5	1	6
SSA_Ex	-2	18	15	-2	17	2	18
RoAFR	1	3	4	1	3	1	5
SASIA-Ex	-9	1	-8	-9	1	0	-8
RoHIA	0	0	0	0	0	0	0
RoASIA	2	1	3	2	1	0	3
Oceania	0	8	8	0	8	1	8
World	**506**	**288**	**794**	**829**	**213**	**240**	**1,283**

A comparative summary of all the policy scenarios depicting the role of marginal lands is presented in Table 14. The U.S. corn ethanol mandate of increase to 15 billion gallons per year by 2015, starting from 2001 base, is an exogenous increment of 1.17 exa joules on energy basis. This mandate results in emission of 22.6 grams of CO_{2E} per mega joule of ethanol produced, when the there are no marginal lands in the model. After incorporating the CRP land and cropland-pasture in the model, the emissions increased to 36 g CO_{2E}/MJ of ethanol when the CRP quantity or its real rent are not fixed. This is mainly due to the fact that, the forest cover experienced much larger reductions when the new marginal lands are incorporated into the model. Though the new marginal lands, as expected lessened the impact on pasture-cover, they also resulted in contrasting impact on forest cover.

Table 14. Global Land-Use Emissions across different Biofuel Policy Scenarios

	U.S. 15 bgy (2001-2015)	U.S. & EU Mandate (2006-2015)
Biofuels increment (EJ)	1.17	1.68
Total Emission of CO2e	*Million Metric Tons of CO2e*	
(i) Model with No Marginal Lands	794.1	2138.9
(ii) Model with Marginal Lands	1265.6	3825.7
(iii) CRP land fixed	1282.6	3936.5
(iv) CRP land released	1274.7	4003.6
Emission per MJ of Biofuel	*Grams of CO2e emitted / MJ of Biofuel*	
(i) Model with No Marginal Lands	22.60	42.38
(ii) Model with Marginal Lands	36.00	75.82
(iii) CRP land fixed	36.48	78.02
(iv) CRP land released	36.26	79.34

Note: The land use emissions estimated here are based on the physical land cover change results. It is important to note that following Hertel *et al*. (2010b), we have used the value of effective cropland adjustment (ETA) parameter as 0.66 in estimating the acres of land cover change in this paper.

Interestingly, the emissions did not change much when the quantity of CRP land was fixed or released (36 g CO_{2E}/MJ). This implies that bringing in marginal lands under cultivation substantially increased the indirect land use emissions. It is important note that since the biofuels induced pasture cover change in the model with marginal lands is considerably low; the emissions are higher compared to that of the model with no marginal lands. This is because, in the model with marginal lands, as more of cropland-pasture and less of pasture-cover get converted, the net impact is such that it results in further reduction in forest cover. Since forest cover change results in large scale carbon flux (as implied in Table 11), even a small decline in forest cover would lead to large increase in emissions.

Furthermore, the U.S. and EU mandate experiment which involved a total exogenous increase in biofuels by 1.68 EJ by 2015 starting from the baseline 2006, showed very high emission rates. Though the model with marginal lands showed substantially larger land use emissions, the role of CRP land restrictions did not make much difference in the emission levels. This may be attributed to the fact that availability of CRP land further boosted acreage expansion in feedstock crops with lesser reduction in acreage under other crops, but the global impact on forest and pasture cover remain unchanged.

6. Conclusions

As the importance of biofuels across the world as alternative fuels is growing, several concerns are raised particularly on their potential indirect land use emissions. In order to reduce these indirect land use changes which result in global level large scale deforestation or degradation of grasslands, one possibility is to grow biofuel crops in idle croplands or marginal lands. This study offers a novel framework, in which we first identify the marginal lands such as Federal Conservation Reserve Program (CRP) enrolled lands in the U.S., and cropland-Pasture area in the world. We aggregate this data at Agro-Ecological Zonal (AEZ) level and incorporate these additional land categories in the land-supply function and analyze the implications of biofuel policies in a general equilibrium framework.

In this paper, we examine two policy scenarios: (1) U.S. and EU biofuel programs implemented simultaneously for 2015 starting from the baseline 2006, and (2) U.S. corn-ethanol production by 15 billion gallons per year in 2015 from its 2001. In both of these policies we also examine the potential impact of USDA (i) fixing the quantity of CRP land, alternatively (ii) fixing the real rent of CRP (USDA does not defend the CRP rents). The results showed that availability of additional marginal lands reduces the land-cover change substantially; particularly forest degradation which is a major contributor is GHG emissions. The estimated indirect land use emissions showed that the models without marginal lands, put pressure on larger deforestation to meet the demand for cropland required for growing biofuel feedstocks. As more land is available after incorporating the marginal lands, due to fall in price than before, the model predicts much larger conversion of land than the model without the explicit marginal lands. The ILUC emissions were smaller when CRP land is allowed for cultivation. The 15 bgy increment of corn-ethanol only experiment revealed to emit 22.6 g CO_{2E} per MJ of ethanol produced in the U.S. by 2015, when there are no marginal lands in the model. The same experiment implemented by Searchinger *et al*. (2008) showed that it results in 104 g CO_{2E} per MJ of ethanol. However, when the marginal lands are incorporated into the model, the emissions increased to 36 g CO_{2E} per MJ of ethanol.

The key finding of this study is by including cropland-pasture and CRP lands in the land use nest, we acknowledge the relatively greater ease of moving these additional marginal lands back into crops as demand for cropland rises. Since cropland-pasture rents are tied closely to pasture land rents through their substitutability in livestock production, there is a tendency for cropland expansion to come disproportionately at the expense of pasture. This assertion is supported by the econometric work of Lubowski *et al*. (2006), as interpreted in Ahmed, Hertel and Lubowski (2008). However, in this study, with larger forest conversion, the overall GHG emissions intensity of corn ethanol due to ILUC rises by one-third. It is important to note that the carbon emission factors used for marginal lands are same as that of pasture-cover. The relatively smaller carbon factors estimated by several studies as discussed above can result in substantially lesser carbon emission.

One important qualification of this study is that the land supply framework that we have followed here allows for explicit availability of cropland-pasture and CRP lands for cultivation of crops. Due to more elastic land supply in the presence of these additional land uses, the biofuel policy experiments resulted in slightly larger conversion of forest, which however contributes significantly to land use emissions. This needs further investigation as modeling explicit demand for accessible forests was beyond scope of this study. As the agricultural commodity prices are rising and also production of biofuels, there is mounting pressure on bringing in marginal lands under cultivation. With this backdrop, this study offers insights into the potential economy-wide implications of biofuels in the presence of marginal croplands.

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Appendices

Table A1. Land Rental Payments in the U.S. ($ million)

Before Modif'n	Cr. Grains	Other Grains	Oilseeds	Sugar-crops	Other Agri.	Pasture-cover	Forest		
AEZ1	0	0	0	0	0	0	0		
AEZ2	0	0	0	0	0	0	0		
AEZ3	0	0	0	0	0	0	0		
AEZ4	0	0	0	0	0	0	0		
AEZ5	0	0	0	0	0	0	0		
AEZ6	0	0	0	0	0	0	0		
AEZ7	356	424	80	101	2643	2745	29		
AEZ8	317	349	254	34	2265	641	116		
AEZ9	391	152	317	105	1505	119	77		
AEZ10	1770	281	1330	132	4105	404	1435		
AEZ11	832	293	932	16	1940	252	1012		
AEZ12	113	146	311	166	1393	127	2430		
AEZ13	2	22	1	4	75	72	43		
AEZ14	2	3	0	1	22	24	43		
AEZ15	0	1	0	0	5	2	10		
AEZ16	0	0	0	0	1	0	34		
AEZ17	0	0	0	0	0	0	0		
AEZ18	0	0	0	0	0	0	0		
TOTAL	**3784**	**1671**	**3225**	**560**	**13953**	**4387**	**5229**		
After Modif'n	Cr. Grains	Other Grains	Oilseeds	Sugar-crops	Other Agri.	Pasture-cover	Forest	CRP-lands	Cropland-pasture
AEZ1	0	0	0	0	0	0	0	0	0
AEZ2	0	0	0	0	0	0	0	0	0
AEZ3	0	0	0	0	0	0	0	0	0
AEZ4	0	0	0	0	0	0	0	0	0
AEZ5	0	0	0	0	0	0	0	0	0
AEZ6	0	0	0	0	0	0	0	0	0
AEZ7	356	424	80	101	2643	2095	29	189	471
AEZ8	317	349	254	34	2265	502	116	143	97
AEZ9	391	152	317	105	1505	59	77	59	41
AEZ10	1770	281	1330	132	4105	139	1435	428	139
AEZ11	832	293	932	16	1940	75	1012	128	75
AEZ12	113	146	311	166	1393	45	2430	127	45
AEZ13	2	22	1	4	75	60	43	10	9
AEZ14	2	3	0	1	22	20	43	1	3
AEZ15	0	1	0	0	5	2	10	0	0
AEZ16	0	0	0	0	1	0	34	0	0
AEZ17	0	0	0	0	0	0	0	0	0
AEZ18	0	0	0	0	0	0	0	0	0
TOTAL	**3784**	**1671**	**3225**	**560**	**13953**	**2999**	**5229**	**1085**	**881**
Capital endowment in service sector before adjustment								3275607	
Capital endowment in service sector after adjustment								3274522	
Change in capital endowment (= CRP rental payments)								**1085**	

Notes: The upper panel shows the original producer expenditure on land rental payments (measured at agent prices) in each land using sector in the U.S., obtained from the GTAP version-6 data base. The lower panel shows land rental payments after incorporating the CRP-lands and cropland-pasture in the U.S. The CRP payments are obtained from the capital endowment in the government services sector.

Table A2. Land Rents across AEZs in the U.S. ($/acre)

Before modification	Cr. Grains	Other Grains	Oilseeds	Sugar crops	Other Agri.	Pasture-cover	Forest
AEZ7	37	22	59	245	154	8	1
AEZ8	33	22	34	208	157	7	3
AEZ9	42	24	38	192	260	9	3
AEZ10	47	38	42	227	156	10	9
AEZ11	42	49	37	263	101	9	8
AEZ12	35	53	45	234	133	7	15
AEZ13	19	17	23	203	90	4	1
AEZ14	22	25	39	210	98	5	0
AEZ15	26	39	49	0	132	6	0
AEZ16	0	62	0	0	339	0	3

After modification	Cr. Grains	Other Grains	Oilseeds	Sugar crops	Other Agri.	Pasture-cover	Forest	CRP-lands	Cropland-pasture
AEZ7	37	22	59	245	154	6	1	27	20
AEZ8	33	22	34	208	157	6	3	21	16
AEZ9	42	24	38	192	260	5	3	24	19
AEZ10	47	38	42	227	156	5	9	30	11
AEZ11	42	49	37	263	101	4	8	30	6
AEZ12	35	53	45	234	133	4	15	31	9
AEZ13	19	17	23	203	90	3	1	14	10
AEZ14	22	25	39	210	98	4	0	20	14
AEZ15	26	39	49		132	6	0		
AEZ16		62			339	0	3		

Table A3. The Changing Structure of the Biofuel Economy

		US			EU		
Fuel Consumption:	*Units*	2001	2006	2015	2001	2006	2015
Liquid fuels for Transport:							
Petroleum	*Quad Btu*	25.96	27.57	29.63	18.20	18.20	18.50
Total Biofuels[1]	*Quad Btu*	0.150	0.503	1.508	0.037	0.224	1.156
Ethanol	*Quad Btu*	0.149	0.471	1.341	-	0.035	0.183
Biodiesel	*Quad Btu*	0.001	0.032	0.167	0.037	0.189	0.973
Share of biofuels in liquids for transport (energy basis)	*%*	***0.58***	***1.83***	***5.09***	***0.20***	***1.23***	***6.25***
Baseline Experiment		2001	2006		2001	2006	
Biofuel Policies:							
Subsidy for Ethanol	*$/gallon*	0.51	0.51		-	1.00	
Average Price of Ethanol[2]	*$/gallon*	1.48	2.58		1.48	1.96	
Ad valorem equivalent of subsidy		1.34	1.20		1.00	1.51	
% ch in subsidy (2001-2006)			***-10.9***			***51.0***	
Subsidy for Biodiesel[3]	*$/gallon*	1.00	1.00		-	1.90	
Average Price of Biodiesel[4]	*$/gallon*	2.45	3.23		2.33	2.34	
Ad valorem equivalent of subsidy		1.41	1.31		1.00	1.81	
% ch in subsidy (2001-2006)			***-7.0***			***81.2***	

Source: Hertel *et al*. (2010a).

Table A4. Change in Land Use Supply Response and Land Revenue Shares in the U.S.

		Land Revenue Share							*Land Supply Response*						
		Cr. Grains	Other Grains	Oilseeds	Sugar crops	Other Agri	Cropland-pasture	CRP lands	Cr. Grains	Other Grains	Oilseeds	Sugar crops	Other Agri	Cropland-pasture	CRP lands
2001 base data															
Pre-sim	With No Marginal Lands	0.255	0.167	0.095	0.017	0.466	0.000	0.000	0.373	0.417	0.452	0.491	0.267	0.500	0.500
Pre-sim	With Marginal Lands	0.232	0.152	0.087	0.016	0.424	0.024	0.066	0.384	0.424	0.457	0.492	0.288	0.488	0.467
Experiment: 15 bgy corn ethanol increment in the US from 2001 base															
Post-sim	With No Marginal Lands	0.367	0.119	0.076	0.015	0.424	0.000	0.000	0.317	0.441	0.462	0.493	0.288	0.500	0.500
Post-sim	With Marginal Lands	0.343	0.114	0.072	0.014	0.392	0.019	0.046	0.328	0.443	0.464	0.493	0.304	0.491	0.477
Post-sim	Marginal Lands with fixed CRP	0.336	0.109	0.070	0.013	0.388	0.018	0.065	0.332	0.445	0.465	0.493	0.306	0.491	0.467
Post-sim	Marginal Lands with CRP released	0.345	0.115	0.072	0.014	0.393	0.019	0.042	0.327	0.443	0.464	0.493	0.303	0.491	0.479
Experiment: Baseline experiment (2001-2006)															
Post-sim	With No Marginal Lands	0.274	0.157	0.097	0.017	0.455	0.000	0.000	0.363	0.421	0.451	0.492	0.272	0.500	0.500
Post-sim	With Marginal Lands	0.250	0.144	0.090	0.015	0.416	0.023	0.062	0.375	0.428	0.455	0.492	0.292	0.489	0.469
Post-sim	Marginal Lands with fixed CRP	0.249	0.143	0.089	0.015	0.415	0.023	0.066	0.375	0.428	0.455	0.492	0.293	0.489	0.467
Post-sim	Marginal Lands with CRP released	0.250	0.144	0.090	0.015	0.416	0.023	0.062	0.375	0.428	0.455	0.492	0.292	0.489	0.469
Experiment: US & EU 2015 Mandate experiment (2006-2015)															
Post-sim	With No Marginal Lands	0.333	0.123	0.109	0.014	0.421	0.000	0.000	0.333	0.439	0.445	0.493	0.290	0.500	0.500
Post-sim	With Marginal Lands	0.302	0.115	0.104	0.013	0.388	0.017	0.061	0.349	0.443	0.448	0.493	0.306	0.492	0.469
Post-sim	Marginal Lands with fixed CRP	0.304	0.112	0.105	0.013	0.385	0.017	0.065	0.348	0.444	0.448	0.494	0.307	0.492	0.467
Post-sim	Marginal Lands with CRP released	0.315	0.119	0.110	0.013	0.392	0.017	0.034	0.343	0.441	0.445	0.493	0.304	0.491	0.483

Note: "Pre-sim" and "Post-sim" indicate the results before and after the simulation experiments, respectively.