Indirect Land Use Effects of Corn Ethanol in the U.S: Implications for the Conservation Reserve Program

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Abstract

We developed an integrated model of U.S agricultural and transportation sectors to examine the impacts of corn ethanol production on the reduction in CRP enrollment and grassland conversion during the period 2007-2012. We also examine the extent to which ethanol production raised the budgetary cost of maintaining the CRP program at the 2007 level. Our simulation analysis shows that by raising crop prices and increasing opportunity costs of marginal lands, corn ethanol production led to additional 1.6 million acres reduction in CRP enrollment and grassland conversion relative to a no-biofuel policy baseline scenario. In order to maintain the CRP enrollment at the 2007 levels, a net present value of government expenditure of $1.85 billion on reenrollment would be needed under the baseline scenario for the period 2007-2012. Government expenditure will increase to $2.07 billion with the booming of corn ethanol industry.

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Corn ethanol production has grown rapidly from 6.5 billion gallons in 2007 to 13.2 billion gallons in 2012 following the establishment of the Renewable Fuel Standard (RFS) under the Energy Independence and Security Act in 2007. A number of studies have used top-down global partial and general equilibrium models to simulate the impact of the diversion of corn from food and feed to ethanol production on crop prices and indirectly on land use change (Khanna and Crago 2012, Searchinger et al. 2008). These simulation models analyze impacts using aggregate regions and their findings on land use changes are typically not validated by comparison with observed changes in land use. Wright and Wimberly (2013) have used satellite data to examine the loss in grasslands in five states in the western corn-belt in the US, and found that nearly 1.3 million acres of grasslands were converted to cropland during the period 2006-2011. However, they do not isolate the impact of corn ethanol production on the observed change in grasslands in this region, and are unable to distinguish the types of grasslands converted to crop production (for example, idle land, cropland pasture, and land enrolled in the Conservation Reserve Program).

Rising crop prices could induce crop production to expand on to marginal land that may be in a crop-pasture rotation under permanent pasture. It could also induce land enrolled in the Conservation Reserve Program (CRP) to exit the program as contracts expire.[1] Land enrolled in the CRP has been declining since 2007. In 2007, about 36.8 million acres of land were enrolled in the CRP with a total government spending of $1.8 billion. The 2008 farm

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[1] The CRP is a voluntary program that allows farmers to retire their environmentally sensitive cropland for conservation. Since its inception in 1985, the CRP has played an important role in reducing soil erosion, improving water quality, and enhancing wildlife habitat. As estimated, the CRP has reduced soil erosion by about 450 million tons per year and increased duck populations by more than 2 million per year (Usda 2011). To incentivize farmers with highly erodible cropland to participate in the program and establish long-term resource conserving covers, the U.S. Department of Agriculture (USDA) provides soil rental rates (SRR) and cost-share assistance to program participants based on the productivity of the soils within each county and county-average land rents.

bill reduced the size of the CRP to 32 million acres. In 2008, about 2.2 million acres of CRP land left the program, despite a 3% increase in government spending on the program relative to that in 2007 (USDA 2011). Currently the program has a total enrollment of 28 million acres because expiring program acres have chosen to exit the program because of various reasons. Among others, rising crop prices are likely to be the key factor resulting in the reduction in the CRP enrollment, because farmers could earn higher returns from alternative use of the land. Several studies have identified that, among other factors, the rapid growth of U.S. corn ethanol industry was a key driver increasing food commodity prices in 2007/2008, by reducing the supply of corn for food/feed consumption and decreasing the land under other food/feed crops (Hochman et al. 2011).

The purpose of this study is to examine the impact of corn ethanol production during the 2007-2012 period on land use change at the extensive margin in the U.S. In particular, we examine the extent to which biofuels have led to a conversion of land enrolled in the CRP to cropland as well as other marginal land to active crop production over the 2007-2012 period. We analyze the impact of corn ethanol production on food prices and its implications for farmers' decision to re-enroll expiring land in the CRP and for the conversion of other marginal land to crop production. We also estimate the extent to which biofuel production has raised the budgetary cost of maintaining the CRP program at the 2007 level. We examine the sensitivity of our results to various assumptions about the rate of increase in the soil rental rate payments offered to land parcels enrolled in CRP and about the productivity of marginal lands.

The numerical simulation is conducted using a dynamic, multi-market equilibrium model, Biofuel and Environmental Policy Analysis Model (BEPAM), which integrates the agricultural and fuel markets in the U.S. and analyzes the implications of various policy scenarios for fuel, biofuel, food/feed crops and livestock. It endogenously determines

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farmers' land use decisions, including cropland and CRP land. The model considers spatial heterogeneity in crop yields, costs of production and land availability for different land types across regions. The model considers not only first-generation biofuels (such as corn ethanol), but second-generation biofuels produced from a variety of cellulosic feedstocks, including crop and forest residues and energy crops.

Numerical Model

We developed a spatially explicit, price-endogenous, mathematical programming model, Biofuel and Environmental Policy Analysis Model, to examine the impacts of corn ethanol production on U.S. agricultural and transportation fuel sectors (Chen et al. 2014). BEPAM has been used previously to analyze the impacts of various biofuel and climate policies, such as the RFS, a Low Carbon Fuel Standard, and a carbon tax, on U.S. agricultural and transportation fuel markets (Chen et al. 2011, Chen and Onal 2012, Huang et al. 2013). This previous analysis had assumed that land enrolled in the CRP remains fixed at the level in 2007. The present paper extends BEPAM by considering the potential for expiring CRP acres to exit the program and convert land to crop production. It analyzes the incentives for expiring CRP acres to re-enroll in the program both with and without corn ethanol production.

The model simulates market decisions on land allocation, crop production and crop prices by maximizing the sum of consumers' and producers' surpluses in the agricultural and transportation fuel sector subject to various material balances, resource availability and policy constraints (Mccarl and Spreen 1980, Takayama and Judge 1971). The simulation model considers regional differences in crop production activity, where crop yields, costs of production, and resource endowments are specified differently for each region and each crop assuming Leontief production functions. The production costs of row crops vary with

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alternative management practices (rotation, tillage and irrigation choices), while the costs of perennial energy crops vary with the age of the perennials. Yields of conventional crops and perennial energy crops in each region also depend on the types of land used for crop production.

Land is the only limited resource endowment considered in the model. We include six types of land, namely regular cropland, idle land (excluding the land enrolled in the CRP), cropland pasture, CRP land, pasture land, and forestland pasture. We allow the conversion of idle land and cropland pasture to crop production, while keeping the land under pasture land and forestland pasture unchanged over the planning horizon. CRP land can be converted to crops upon expiring if the net returns for crop production are greater than the rental payments paid by the federal government.

Algebraic Equations of the Simulation Model

We now present the algebraic structure of the simulation model. For brevity, we only present a stylized version of the model that includes the agricultural sector to explain how land owners make CRP land-use decisions upon expiring. For convenience, we use lower case symbols to denote exogenous data/parameters and upper case symbols to represent endogenously determined variables. The notations used in the model are as follows:

Sets:

$T = \{t\}$: index set for time periods (years);

$I = \{i, p\}$: index set for crops, where i denotes conventional food/feed crops and p denotes perennial energy crops as biofuel feedstocks;

$R = \{r\}$: index set for crop production regions;

$M = \{m\}$: index set of biofuel type, where $m1$ represents corn ethanol and $m2$ represents cellulosic biofuels;

$L = \{l\}$: index set for land type;

Data/Parameters:

$c_{i,r,l}$, $c_{p,r,l}$: cost per acre of crop i and energy crop p, respectively, in region r on land type l;

$y_{i,r,l}$, $y_{p,r,l}$: yield per acre of crop i and energy crop p, respectively, in region r, land type l;

$s_{r,t}$: soil rental payments offered to CRP land owners in region r in year t;

$al_{r,l,t}$: land availability in region r for land type l in year t;

$cl_{r,t}$: amount of expiring CRP acres in region r in year t;

a_m: biofuel conversion factor for ethanol type m;

$e_{m,t}$: production target for biofuel type m in year t;

$p_i = f_i(q_i)$: inverse demand function for commodity $i \in I$, where p_i, q_i denote the price and quantity, respectively;

Variables:

$Q_{i,t}$: equilibrium level of demand for crop i in year t;

QE_t: amount of corn used for ethanol production in year t;

$X_{i,r,l,t}$ and $X_{p,r,l,t}$: land allocated to crop i and energy crop p in year t in region r under land type l;

$CRPIN_{r,t}$: amount of expiring CRP land that will reenroll in the program in region r and year t;

$CRPOUT_{r,t}$ amount of expiring CRP land that will be converted to crops.

   With this notation, the following model determines the optimum regional land use decisions for producing food/feed and energy crops and resulting market equilibrium in agricultural commodity markets over a planning horizon of T years:

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$$Max \sum_{t \in T} \left(\sum_{i \in I} \int_0^{Q_{i,t}} f_i(q_i) dq_i + \sum_{r \in R} s_{r,t} CRPIN_{r,t} - \sum_{i \in I, r \in R, l \in L} c_{i,r,l} X_{i,r,l,t} - \sum_{p \in I, r \in R, l \in L} c_{p,r,l} X_{p,r,l,t} \right) \quad (1)$$

such that:

$$Q_{i,t} + QE_{t\,|i=corn} \leq \sum_{r \in R, l \in L} y_{i,r,l} X_{i,r,l,t} \quad \text{for all } i \in I, t \in T \quad (2)$$

$$\alpha_{m1} QE_t \geq e_{m1,t} \quad \text{for all } t \in T \quad (3)$$

$$\alpha_{m2} \sum_{p \in I, r \in R, l \in L} y_{p,r,l} X_{p,r,l,t} \geq e_{m2,t} \quad \text{for all } t \in T \quad (4)$$

$$\sum_{i \in I} X_{i,r,l,t} + \sum_{p \in I} X_{p,r,l,t} \leq al_{r,l,t} \quad \text{for all } r \in R, l \in L, t \in T \quad (5)$$

$$CRPIN_{r,t} + CRPOUT_{r,t} \leq cl_{r,t} \quad \text{for all } r \in R, t \in T \quad (6)$$

$$al_{r,l,t} = \sum_{1 \leq t' \leq t} CRPOUT_{r,t'} \quad \text{for all } r \in R, t \in T \text{ and } l = CRP \quad (7)$$

$$Q_{i,t}, QE_t, X_{i,r,l,t}, X_{p,r,l,t}, CRPIN_{r,t}, CRPOUT_{r,t} \geq 0 \quad (8)$$

The objective function represents the sum of consumers' and producers' surpluses from the agricultural sector, which is given by the sum of areas under the crop demand functions and total soil rental payments received for re-enrolled CRP land, net of total crop production costs. For simplicity, the stylized model does not consider various processed goods, livestock production activities, demands for livestock commodities, and byproducts of crop processing (namely soybean crushing and corn ethanol production whose byproducts are used as livestock feed), and the use of crop residues (corn stover and wheat straw) and forest residues as cellulosic biofuel feedstock, which are all incorporated in the empirical model. The cost of biofuel processing is also excluded in the objective function in this mandate analysis. In the optimum solution the blending mandate constraints (3) and (4) will be satisfied as strict equalities, therefore the total processing cost will be a constant in the objective function and will not affect the optimum solution regardless of the number and location of processing

facilities built. The terminal value of the remaining economic life of standing perennial grasses beyond the planning period T is also incorporated in the objective function.

Constraint (2) establishes the material balance for the production and usage of conventional crops. Note that the amount of corn used for ethanol production only appears on the left side of the constraint as an additional demand for corn. Constraints (3) and (4) state that the amount of biofuels derived from corn and cellulosic biomass should meet their respective production targets.

Constraint (5) restricts that the land used for conventional crops ($X_{i,r,l,t}$) and perennial energy crops ($X_{p,r,l,t}$) cannot exceed the total land availability for each land type ($al_{r,l,t}$). As the CRP contracts expire, some expiring CRP land may stay in the program in return for soil rental payments ($s_{r,t}$), represented by $CRPIN_{r,t}$, while other expiring CRP acreages may be converted to cropland (represented by $CRPOUT_{r,t}$). This land balance is expressed in constraint (6). The shadow values of the constraint (6) are the market equilibrium opportunity costs of expiring CRP land (this can be shown by using the Karush-Kuhn-Tucker first order optimality conditions). If the shadow values of constraint (6) are greater than soil rental payments offered ($s_{r,t}$) in a region, then the expiring CRP land in that region will be converted for crop production. On the other hand, if the shadow values of constraint (6) are smaller than $s_{r,t}$ in that region, farmers will reenroll their expiring CRP land in the program. Constraint (7) states that the total amount of CRP land available for crop production in year t is the sum of the expiring CRP acreages that leave the program in all previous years $t' \leq t$. Finally (8) imposes non-negativity restrictions for the endogenous variables.

The purpose of this study is to examine the impact of corn ethanol production on land use change over the period 2007-2012. Since cellulosic ethanol was not commercially produced

over this period, we set $e_{m2,t} = 0$ in constraint (4), which results in $X_{p,r,l,t} = 0$, and use observed corn ethanol production to set the mandate for corn ethanol in constraint (3).

Data

The agricultural sector of the BEPAM includes fifteen conventional crops, eight livestock products, two energy crops, crop residues from the production of corn and wheat, forest residues, various processed commodities, and co-products from the production of corn ethanol and soybean oil. In the crop and livestock markets, primary crop and livestock commodities are consumed either domestically or traded with the ROW (exported or imported). The primary crop commodities can also be processed or directly fed to various animal categories. Domestic and export demands and import supplies are incorporated by assuming linear price-responsive demand/supply functions. The commodity demand functions and export demand functions for tradable row crops and processed commodities are shifted upward over time at exogenously specified rates.

The model considers the 295 Crop Reporting Districts (CRDs) in 41 US states as spatial decision units and incorporates the heterogeneity in crop and livestock production across these CRDs. Production costs and yields of individual crop/livestock activities and resource endowments are specified differently for each CRD based on crop/livestock budgets reported by various agricultural experiment stations and the National Agricultural Statistics Service (NASS) database. A detailed description about elasticities used to calibrate domestic and export demand and import supply curves, data used to construct crop production costs, and the transportation sector of the BEPAM can be found in Chen et al. (2014). Here, we report data sources related to marginal lands, including historical CRP enrollment and soil rental payments, and the assumptions made about crop productivity on marginal lands.

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The model includes several types of land, namely regular cropland, CRP land, idle land (without CRP land), cropland pasture, pasture land, and forestland pasture, for each CRD. Expiring CRP land, idle land, and cropland pasture can be converted to conventional crops, while other lands, including pasture land and forestland pasture, are assumed to be fixed at 2007 levels. Data on idle cropland, cropland pasture, pasture and forestland pasture for each CRD are obtained from USDA/NASS (2010). CRD-specific planted acres for fifteen conventional crops are used to obtain available regular cropland in 2007 (estimated at 304 million acres for the 295 CRDs considered here). The sum of availability of idle land (without CRP) and cropland pasture is estimated to be 37.5 million acres in 2007. Total CRP enrollment was reported to be 36.6 million acres in 2007, of which about 28.5 million acres (78%) were covered with native bunchgrasses and grasslands, while the rest (8.1 million acres) was primarily covered with trees, such as shade trees and riparian buffers. In 2007, the availability of pastureland and forestland pasture is estimated to be 383 million acres and 26 million acres, respectively.

Yearly county-level CRP contract data are obtained from the Farm Service Agency of the U.S. Department of Agriculture. The dataset includes CRP contracts for 2332 counties in 36 states from 1986 to 2012 (FAS 2012). This data set includes average rental rate at each signup (i.e., a specified enrollment period), and CRP acres enrolled during each signup in each county. We aggregate the county level CRP data to the CRD level in the empirical analysis for ease of computation.

We use the historical five year average (2003-2007) yield per acre for each CRD to calculate yields of conventional crops for that CRD. The yields of major crops (such as corn, soybeans, and wheat) are assumed to increase over time at the trend rate estimated using historical data. These yields are also assumed to be price-elastic with the price elasticities estimated econometrically. The trend rates and elasticities used in the model and more details

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of the econometric estimation methods can be found in Chen et al (2014). With the lack of observed crop yields on marginal lands, we assume that crop yields on CRP land, idle land, and cropland pasture are 66% of that on regular cropland. This assumption is similar to that made in Hertel et al (2010). We will test sensitivity of our results to alternative assumptions on crop yields on marginal lands and yield growth rates.

Results

We first validate the numerical model, assuming existing fuel taxes, actual corn ethanol production (see Figure 1), ethanol tax credit and import tariff on Brazilian sugarcane ethanol, and compare results on total CRP enrollment with observed values for years 2007-2012. As shown in Figure 2, we find that the model simulates farmers' enrollment(exit) decisions of expiring CRP lands well; the percentage discrepancies between simulated total CRP enrollment and observed CRP acreages are typically less than 2% for the 2007-2012 period.

We then use the model to simulate CRP enrollment and grassland conversion under a Business-as-Usual (BAU) scenario defined without any biofuel policies, such as the biofuel mandate, ethanol tax credit and import tariff. Thus, demand for corn ethanol under the BAU scenario is primarily driven by the demand for ethanol as a fuel oxygenator. We compare total CRP enrollment and grassland conversion with corn ethanol production to those under the BAU scenarios to examine the extent to which the reductions in CRP enrollment and grassland conversion during the period 2007-2012 were caused by corn ethanol production. We also evaluate how much corn ethanol production contributed to the rising commodity prices during this period and examine the implications for the costs of maintaining the CRP.

Reductions in CRP land and grassland induced by corn ethanol production

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Under the BAU scenario, if soil rental payments offered to farmers remain at the levels when they signed up, about 1.1 million acres of the expiring CRP land would leave the program for conventional crop production in 2007, with a remaining of 35.9 million acres in the program (Figure 2). That is primarily due to the increases in crop yields and food prices over the past decade, both of which raised the opportunity costs of using CRP land for conservation. Of the 37.5 million acres of grassland, about 52% (19.4 million acres) would be converted to cropland in 2007 due to higher returns from crop production (see Figure 3). Grassland conversion would remain between 19.4-19.7 million acres during the period 2007-2012 (Figure 3). As more CRP contracts became expiring, reduction in CRP enrollment would increase to 9.2 million acres by 2012 even without the mandate for corn ethanol production (see Figure 2).

By diverting land from food crops to biofuel crops, the production of corn ethanol would increase corn, soybean, and wheat prices in 2012 by 32%, 22%, and 3%, respectively, relative to the BAU scenario (Figure 4). That further raised the opportunity costs of CRP land and grassland. Our simulation results indicate that about 10 million acres of the expiring CRP land would be converted to cropland by 2012, with a remaining of 27.1 million acres of CRP enrollment in 2012, which is almost identical to observed CRP acreage in 2012 (Figure 2). Increased crop prices would also induce a net conversion of 20.4 million acres of grassland to crop production in 2012. Therefore, corn ethanol production contributed to the reduction in CRP enrollment by 8.7% (0.8 million acres) and grassland conversion by 4.1% (0.8 million acres) during the 2007-2012 period as compared to the BAU scenario.

Figure 5 shows regional CRP land and grassland conversion in 2012 with corn ethanol production. We find that most of converted CRP land would be concentrated in states having comparative advantage in producing corn, such as Kansas, N. Dakota, Texas, Missouri, Nebraska, Iowa, and Illinois (Figure 5(a)). Together these states would account for more than

67% of the total CRP land converted to cropland. On the other hand, grassland conversion would occur mostly in Texas, Missouri, Montana, Kansas, and S. Dakota with a large stock of grassland and high wheat and alfalfa yields (see Figure 5(b)).

Crop prices and land use change

Because of converted CRP land and grassland for crop production, total cropland with corn ethanol production would be 0.8 million acres larger as compared to the BAU scenario in 2012, with a total amount of 334.4 million acres, consisting of 304.1 million acres of regular cropland (91%), 10 million acres of CRP land that exited the program (3%), and 20.4 million acres of converted grassland (6%) (see Table 1). Compared to the BAU scenario, additional 23 million acres of cropland in 2012 would be diverted to corn ethanol production, while the land for food crops would decline by 21.4 million acres. As a result, corn, soybean, and wheat prices in 2012 with corn ethanol production would be 32%, 22%, and 3% higher, respectively, than crop prices under the BAU scenario (Figure 4). If CRP acreages were maintained at the 2007 levels and could not be converted for crop production, corn, soybean, and wheat prices would be 5.9%, 5.3%, and 1.6% higher, respectively, than otherwise (see Figure 4).

Corn ethanol production increased the land under corn by 19.4 million acres in 2012 relative to the BAU scenario, and reduced the land under other crops by 17.8 million acres. The increase in land under corn came entirely from the reductions in land previously under other food/feed crops, such as soybeans, wheat, rice, sorghum, cotton, and alfalfa. Additional converted CRP land and grassland due to corn ethanol production (1.6 million acres in total) were primarily used for the production of wheat and alfalfa because of the comparative advantage in producing the two crops on marginal lands.

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Maintenance costs of the CRP

If the CRP enrollment were maintained at the 2007 levels, a net present value of government expenditure of $1.85 billion on reenrollment would be needed under the BAU scenario for the period 2007-2012. That includes $0.33 billion for expiring CRP acres that chose to renew their contracts and $1.52 billion to incentive farmers with expiring CRP acres who decided to leave the program for crop production to renew their contracts (Table 2). With corn ethanol production, total CRP maintenance cost will increase to $2.07 billion, which is $0.22 billion (11.8%) higher relative to the BAU scenario.

Sensitivity analysis

We examine the sensitivity of our model results to some key parameters affecting farmers' reenrollment decisions on expiring CRP land in Scenarios (1)-(3). Specifically, in Scenario (1), we assume yields of conventional crops on marginal lands to be 33% of that on regular cropland. In Scenario (2), we consider a pessimistic case where yield growth rates of corn, soybean, and wheat are only 50% of those assumed in the benchmark case. In Scenario (3), we use a discount rate of 2% rather than 4% assumed in the benchmark case to examine the implications for maintenance costs of CRP. We examine how these assumptions affect the conversion of CRP land and grassland and the maintenance costs of the program. Results are presented in Figure 6.

In Scenarios (1) and (2) where crop yields on marginal lands are assumed to be lower than that in the benchmark case, reductions in total CRP enrollment and the stock of grasslands are smaller than in the benchmark case, as shown in Figures 6(a)-(b). Specifically, we find that total CRP acreages in 2012 in Scenarios (1) and (2) are 1.7 and 0.9 million acres (6% and 3%) larger, respectively, than that in the benchmark scenario, while grassland conversions in the two scenarios are 1.1 and 0.4 million acres (5% and 2%) smaller. As a

result, total maintenance costs of CRP in Scenarios (1)-(2) are $1.0 billion and $0.95 billion, respectively, over the period 2007-2012 with corn ethanol production (see Figure 6(a)), which are 51% and 6% smaller than that in the benchmark case. Our results on land use changes are not sensitive to the chosen discount rate, as shown in Figures 6(a)-(b). However, with a low discount rate of 2%, discounted total maintenance costs of the program are estimated to be 6% higher than that in the benchmark case (Figure 6(c)).

Conclusions

In this paper, we developed an integrated model of U.S agricultural and transportation sectors to examine the impacts of corn ethanol production on the reduction in CRP enrollment and grassland conversion during the period 2007-2012. We also examine the effect of corn ethanol production on crop prices and the extent to which ethanol production raised the budgetary cost of maintaining the CRP program at the 2007 level.

Our simulation analysis shows that by raising crop prices and increasing opportunity costs of marginal lands, corn ethanol production led to additional 1.6 million acres reduction in CRP enrollment and grassland conversion relative to a no-biofuel policy baseline scenario. Most converted CRP land would be concentrated in states having comparative advantage in producing corn, such as Kansas, N. Dakota, Texas, Missouri, Nebraska, Iowa, and Illinois, while grassland conversion would occur mostly in Texas, Missouri, Montana, Kansas, and S. Dakota with a large stock of grassland and high wheat and alfalfa yields. In order to maintain the CRP enrollment at the 2007 levels, a net present value of government expenditure of $1.85 billion on reenrollment would be needed under the baseline scenario for the period 2007-2012. Government expenditure will increase to $2.07 billion with the booming of corn ethanol industry.

Our results are sensitive to the assumptions about crop productivity on marginal lands. Our analysis indicates that with lower crop yields on marginal lands, the reductions in the sum of CRP enrollment and grasslands could be 1.3-2.8 million acres smaller than that in the benchmark scenario. However, the percentage increase in total CRP maintenance costs with corn ethanol production relative to the corresponding no-biofuel policy baseline scenarios remains comparable across various scenarios considered in the sensitivity analysis, ranging between 8-12%. Results presented here shed light on the continued debate on the impact of corn ethanol production on land use change and food prices in the past decade.

Table 1: Land use change in 2012 (million acres)

	Business-as-usual	Corn ethanol production	Change
Total marginal land[1]	74.1	74.1	
Total cropland	332.8	334.4	1.6
Regular cropland	*304.1*	*304.1*	-
Converted CRP land	*9.2*	*10.0*	*0.8*
Converted grassland	*19.6*	*20.4*	*0.8*
Food crops	323.1	301.7	-21.4
Corn for food	*73.3*	*69.7*	*-3.7*
Other food/feed crops	*249.8*	*232.1*	*-17.8*
Corn for ethanol	9.7	32.7	23.0
Corn	83.0	102.4	19.4
regular cropland	*80.1*	*100.7*	*20.6*
marginal land[1]	*2.9*	*1.7*	*-1.2*
Other food/feed crops	249.8	232.1	-17.8
regular cropland[1]	*223.9*	*203.3*	*-20.6*
marginal land	*25.9*	*28.7*	*2.8*

[1]Marginal land includes CRP land and grassland.

Table 2: Costs of maintaining the CRP at the 2007 levels (Billion \$)[1]

	Business-as-usual	Corn ethanol production	Change
Re-enrolled CRP lands (a)	0.33	0.30	-0.03
Profits of converted CRP land to cropland (b)	1.52	1.77	0.25
Total (d=a+b)	4.13	4.34	0.22

[1] Reenrollment costs of CRP include payments for re-enrolled CRP acreage upon expiring (a), and the payment needed to incentive farmers who decide to convert expiring CRP land to cropland to renew their contracts (b). Costs are discounted for the period 2007-2012, assuming that the CRP enrollment is kept at the 2007 levels.
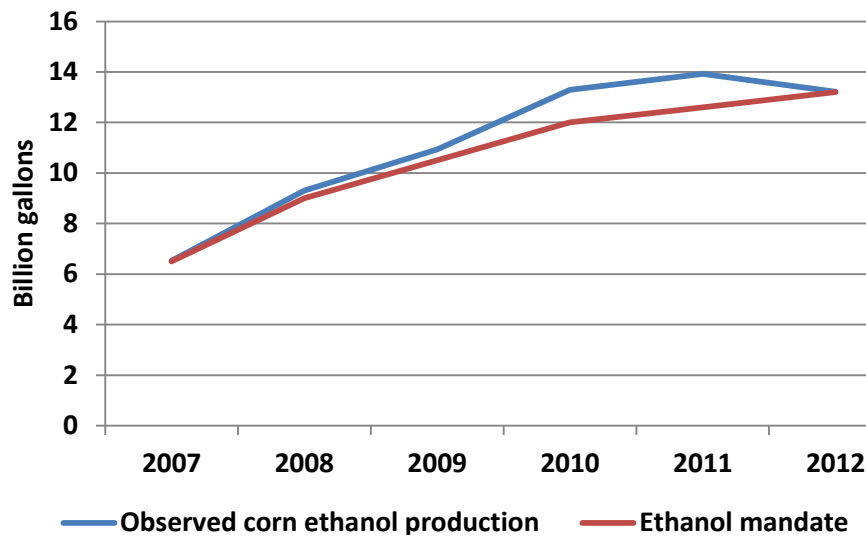
Figure 1. Actual corn ethanol production and the RFS mandate between 2007-2012 (billion gallons)
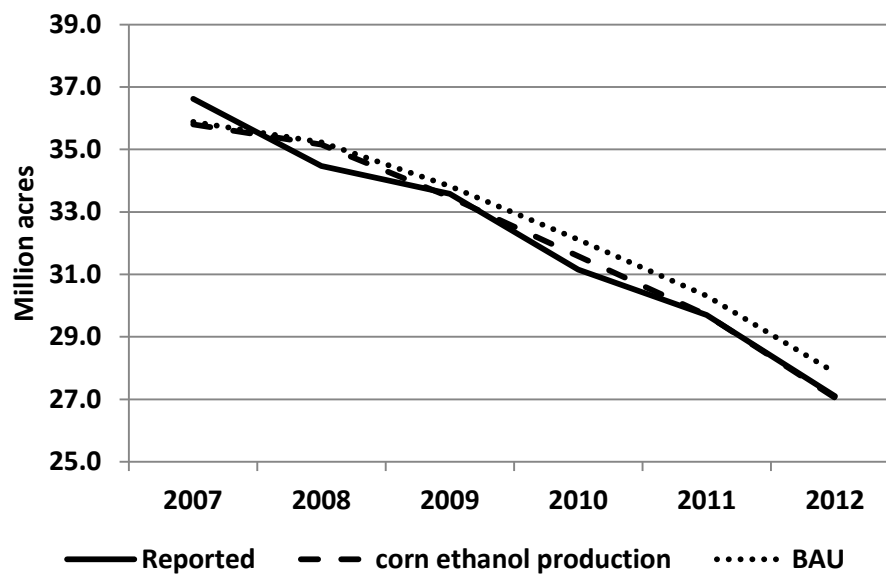
Figure 2. Simulated and observed CRP enrollment between 2007-2012 (million acres)
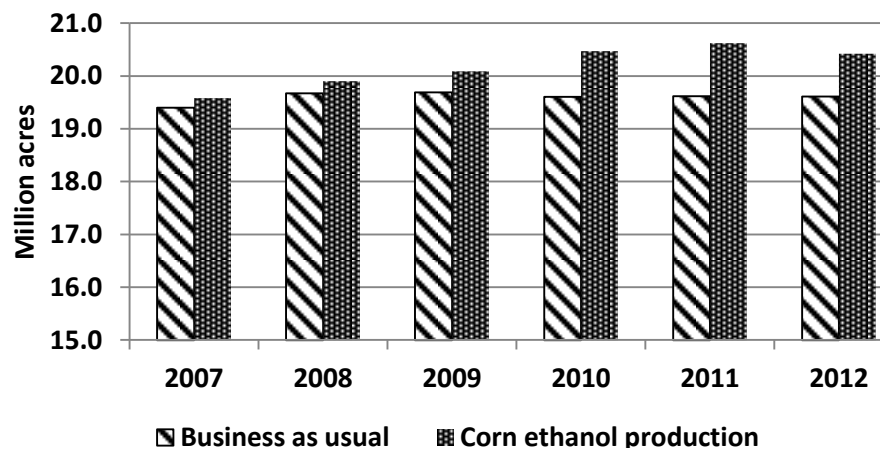
Figure 3. Reductions in grassland between 2007-2012 (million acres)
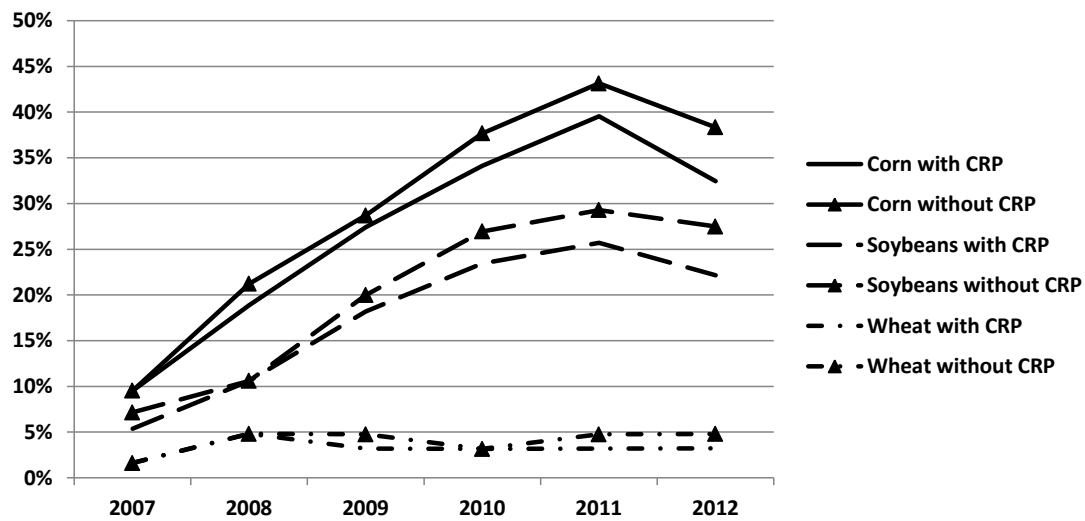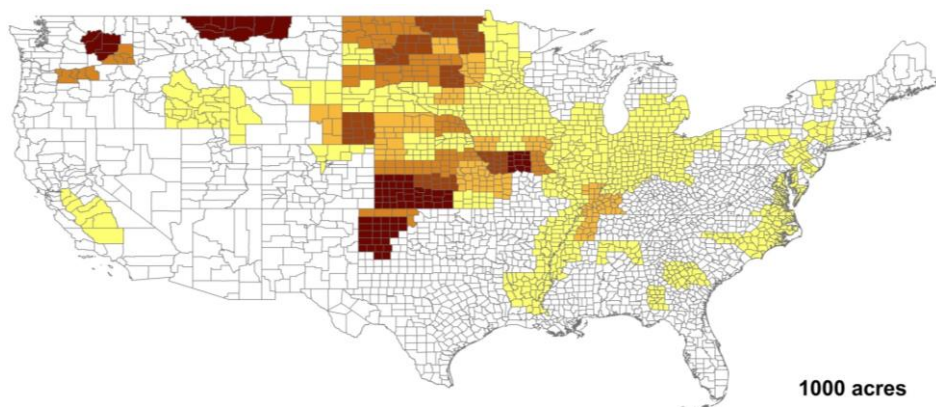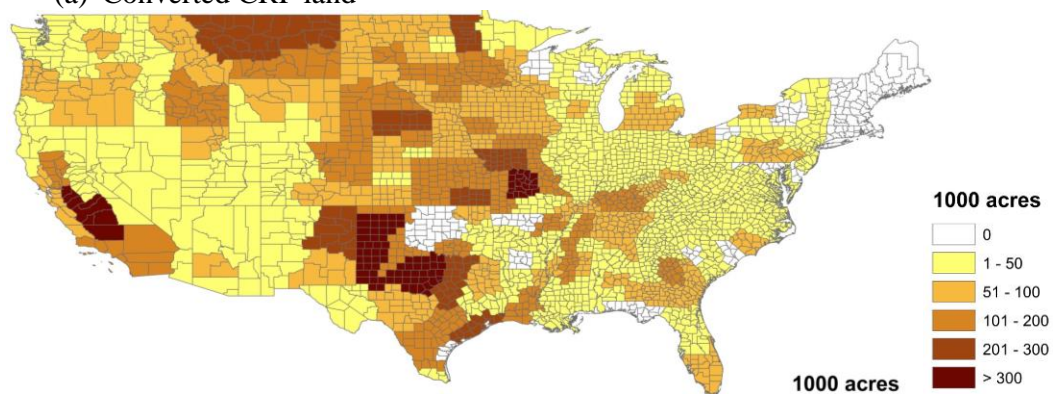Note: total grassland was 37.5 million acres in 2007.

Figure 4. Percentage increase in crop prices under the RFS relative to the BAU scenario
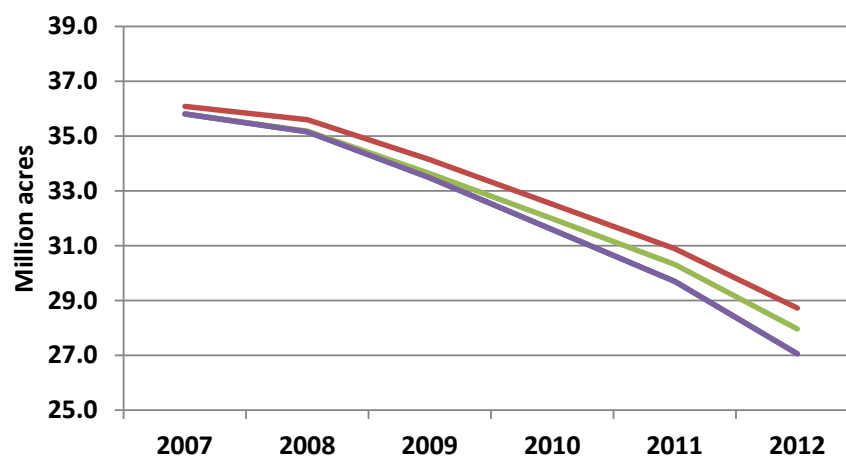
(a) Converted CRP land
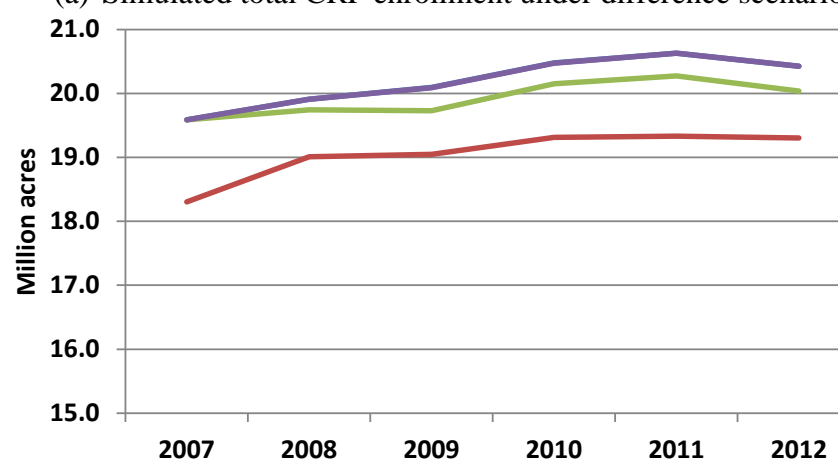

(b) Converted grassland

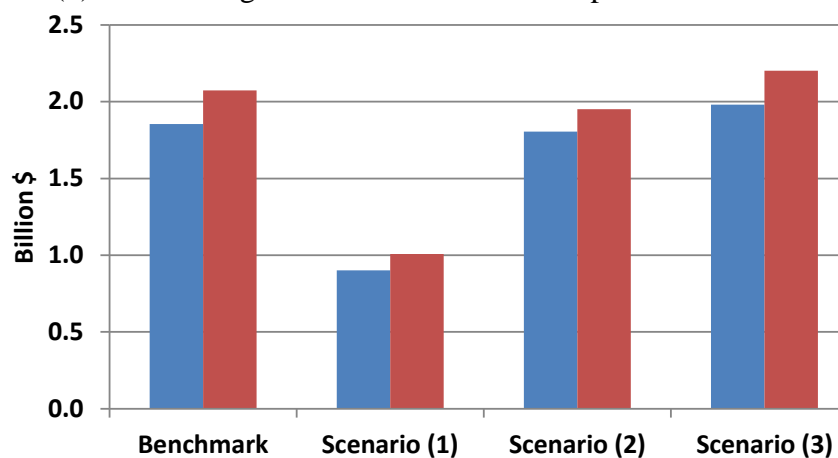**Figure 5. Conversion of marginal lands by 2012 with corn ethanol production (1000 acres)**

(a) Simulated total CRP enrollment under difference scenarios

(b) Simulated grassland conversion to cropland

(c) Maintenance costs of CRP

Figure 6. Sensitivity analysis
Scenario (1) assumes yields of conventional crops on marginal lands to be 33% of that on regular cropland. Scenario (2) considers a low growth rate of major crops. Scenario (3) assumes a discount rate of 2%.

References:

(United States Department of Labor., 2010) Databases, Tables & Calculators by Subject. http://www.bls.gov/data/.

Chen, X., H. Huang, M. Khanna, and H. Onal (2011) Meeting the Mandate for Biofuels: Implications for Land Use and Food and Fuel Prices, Working Paper No. 16697 (http://www.nber.org/papers/w16697).

Chen, X., H. Huang, M. Khanna, and H. Önal. 2014. "Alternative transportation fuel standards: Welfare effects and climate benefits." *Journal of Environmental Economics and Management* 67(3):241-257.

Chen, X., and H. Onal. 2012. "Modeling Agricultural Supply Response Using Mathematical Programming and Crop Mixes." *American Journal of Agricultural Economics* 94(3):674-686.

Hertel, T.W., W.E. Tyner, and D.K. Birur. 2010. "The Global Impacts of Biofuel Mandates." *The Energy Journal* 31(1):75-100.

Hochman, G., D. Rajagopal, G. Timilsina, and D. Zilberman. "The Role of Inventory Adjustments in Quantifying Factors Causing Food Price Inflation." WPS 5744, Policy Research Working Paper, World Bank, Washington DC.

Huang, H., M. Khanna, H. Önal, and X. Chen. 2013. "Stacking low carbon policies on the renewable fuels standard: Economic and greenhouse gas implications." *Energy Policy* 56(0):5-15.

Jain, A., M. Khanna, M. Erickson, and H. Huang. 2010. "An Integrated Bio-geochemical and Economic Analysis of Bioenergy Crops in the Midwestern United States." *Global Change Biology BioEnergy* 2(5):258-277.

Khanna, M., and C.L. Crago. 2012. "Measuring indirect land use change with biofuels: Implications for policy." *Annual Review of Resource Economics* 4:161-184.

McCarl, B.A., and T.H. Spreen. 1980. "Price Endogenous Mathematical Programming as a Tool for Sector Analysis." *American Journal of Agricultural Economics* 62(1):87-102.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change." *Science* 319(5867):1238-1240.

Takayama, T., and G.G. Judge. 1971. *Spatial and Temporal Price and Allocation Models.* Amsterdam: North Holland Publishing Co.

USDA (2011) Conservation Reserve Program and Conservation Reserve Enhancement Program. Washington, U.S. Department of Agriculture.

Wright, C.K., and M.C. Wimberly. 2013. "Recent land use change in the Western Corn Belt threatens grasslands and wetlands." *Proceedings of the National Academy of Sciences* 110(10):4134-4139.