Effect of Corn Ethanol Production on Conservation Reserve Program Acres in the US

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Abstract:

The decline in acres enrolled in the Conservation Reserve Program (CRP) since 2007 while corn ethanol production increased has raised concerns about the indirect land use change effects of biofuel production in the US. However, the extent to which this decline in CRP acres can be causally attributed to increased ethanol production is yet to be determined. Using a dynamic, partial equilibrium economic model for the US agricultural sector we find that doubling of corn ethanol production over the 2007-2012 period (holding all else constant) led to the conversion of 3.2 million acres of marginal land, including 1 million acres in CRP, to crop production. While substantial in magnitude, we find that this represented 13% and 16% of the reduction in all marginal acres and in CRP acres, respectively, that would have occurred in the counterfactual baseline over the 2007-2012 period. We also find that the land use change per million gallons of corn ethanol has declined non-linearly from 453 acres to 112 acres over the 2007-2012 period.

Acknowledegment:

JEL Codes: C61, Q24

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Key words: Corn ethanol, food prices, Conservation Reserve Program, cropland-pasture

JEL codes: Q15, Q16

Ethanol production led to conversion of 3.2 million acres of marginal land, including 1 million acres in CRP, to cropland

I. Introduction

There has been considerable concern about the potential for conversion of marginal land to crop production both in the US and globally, due to higher crop prices induced by the expansion in corn ethanol production in response to the Renewable Fuel Standard (RFS) since 2007. Corn ethanol production was 6.5 billion gallons in 2007 and more than doubled to 13.2 billion gallons in 2012. Over the same period, studies show that there has been an expansion in cropland acres and a decline in non-cropland acres. Specifically, satellite data show a decline in land enrolled in the Conservation Reserve Program (CRP) and other types of grasslands and a corresponding increase in cropland in the US since 2007 (Lark *et al* 2015, Wright and Wimberly 2013). USDA's Farm Service Agency data indicate that land enrolled in the CRP declined by 7.2 million acres, from 36.7 million acres in 2007 to 29.5 million acres in 2012. About 58% of enrolled parcels with expiring contracts chose to exit the program[1], despite a 24% increase in average land rental payments per acre to new lands enrolling in CRP between 2007 and 2012. Wright et al (2017) estimate that 4.2 million acres of arable non-cropland were converted to crop production within 100 miles of refinery locations between 2008 and 2012; this included 3.6 million acres of converted grassland. This has raised concern because conversion of non-cropland to crop production could release carbon stocks in soils and vegetation and create a carbon debt that would offset the greenhouse gas savings achieved by displacing gasoline by biofuels (Fargione *et al* 2008, Searchinger *et al* 2008, Gelfand *et al* 2011).

These data implicitly implicate corn ethanol as the primary cause of this conversion of noncropland to crop production since it occurred in the same area as the expansion in ethanol production and/or over the same period of time. Other studies have questioned this implication

[1] See https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index

(Rashford *et al* 2011, Barr *et al* 2011, Swinton *et al* 2011). Barr et al. (2011) show that the large increases in cropland rents of 56-64% (2007-2009) in the US were accompanied by very small increases of 0.3-3.0% in total US cropland, implying that crop acreage has been relatively inelastic to biofuel-induced land rent increases.

The above studies have not isolated the extent to which the observed increase in total US cropland can be attributed specifically to the increase in corn ethanol prsoduction since 2007. Isolating this impact is complicated because it involves comparison of observed changes in total US cropland and marginal land with biofuels to an unobserved counter-factual without the increase in biofuels while holding all other factors constant. It also requires estimating the land use impacts simultaneously with the effects on crop prices since the latter influences the returns to cropland and the incentives to convert marginal land to cropland.

Several studies have used large-scale general and partial equilibrium numerical models to simulate the effect of biofuel policies on food prices and land use (see review in Khanna, Zilberman, and Crago 2014). For instance, Hertel et al. (2010) and Searchinger et al. (2008) use the Global Trade Analysis Project (GTAP) and Food and Agricultural Policy Research Institute (FAPRI) models, respectively, to examine the direct and indirect land use changes due to corn ethanol production. Beach and McCarl (2010) use the Forest and Agricultural Sector Optimization Model (FASOM) to analyze the least cost mix of alternative biofuels to meet the RFS and their GHG implications. Recent estimates using the GTAP model of 184 acres per million gallons (Taheripour et at., 2017a) and 74 acres per million gallons (Taheripour et al. 2017b) are substantially smaller than an earlier estimate of 456 acres per million gallons (Taheripour and Tyner, 2013) due to changes in modeling assumptions particularly related to the potential for intensification of crop production on cropland. These studies have either assumed that land enrolled in CRP is fixed at 2007 levels and not analyzed the effects of corn ethanol production on the acres enrolled in the CRP or they do not distinguish between marginal land that is in CRP, idle or used for pasture/grazing. Moreover, these studies are estimating land use change due to corn ethanol at a single point in time, and do not consider the dynamics of land use change with increasing production of corn ethanol over time.

A key objective of this paper is to examine the extent to which the observed reduction in CRP acres can be attributed to corn ethanol production over the 2007-2012 period. In particular, we examine the incentives for land enrolled in CRP but with an expiring contract to re-enroll in the program or convert to crop production. We also examine the incentives for other marginal land, cropland pasture, to convert to active crop production. Cropland pasture are defined as a separate category from cropland; the latter includes acres in active crop production only[2]. We undertake this analysis by applying a dynamic, multi-sector, open economy, partial equilibrium economic model, the Biofuel and Environmental Policy Analysis Model (BEPAM), to conduct a with and without analysis of the effect of increased corn ethanol production on the conversion of marginal land to crop production in the US over the 2007-2012 period (Khanna et al., 2011; Chen et al. 2014; Hudiburg et al. 2016). We use a dynamic definition of marginal land that is available for crop production. It is defined as including land enrolled in the CRP with an expiring contract each year. It also includes land defined as cropland-pasture in 2007. BEPAM integrates the agricultural and transportation fuel sectors in the US to simulate the effects of a policy induced change in biofuel production on the equilibrium prices and quantities in markets for

[2] Cropland pasture acres as defined and measured here are distinct from cropland acres and refer to land that could be used for crop production or used for grazing. It is land that is intermittently in crop production (ttps://www.ers.usda.gov/data-products/major-land-uses/glossary.aspx). We distinguish these from cropland acres that are continuously under active crop production. This is different from the definition of cropland in GTAP, which includes cropland pasture (Taheripour and Tyner, 2017).

fifteen major crops, eight types of livestock products, three types of biofuels and their by-products and land. A key contribution of our modeling approach is that it incorporates spatially and temporally heterogeneous economic incentives for changes in the allocation of land from one use to another at a crop reporting district (CRD) level for each of the 295 such districts in the US.

We extend BEPAM to examine the extent to which corn ethanol production might have led to an increase in crop prices and induced the conversion of marginal land to crop production, and/or to changes in cropland use as acreage shifted from one crop to another crop. The dynamic optimization model enables us to incorporate the choice for land enrolled in CRP with expiring contracts to return to crop production or re-enroll in the program by comparing the future stream of returns to land between the two choices. To isolate the impact of corn ethanol production on the conversion of marginal land and on crop prices, we simulate two scenarios with the BEPAM that differ in their levels of ethanol production, while keeping all other modeling assumptions the same. Scenario 1 keeps "Ethanol fixed at the 2007 level" while in Scenario 2 "Ethanol is at the observed levels with RFS". More specifically, Scenario 1 maintains corn ethanol production at the 2007 level of 6.5 billion gallons for the duration of the 2007-2012 period. In Scenario 2, corn ethanol production increases from 6.5 billion to 13.2 billion gallons over the 2007-2012 period as observed under the RFS. We compare outcome in these two scenarios to estimate the extent to which the increased demand for corn ethanol led to an increase in crop prices and created incentives for land in CRP and in cropland-pasture to convert to annual crop production during the 2007-2012 period. Our analysis incorporates the changing availability of CRP acres with expiring contracts for conversion to crop production in each of the years as these acres choose whether to re-enroll in the program or to revert back to crop production. It also incorporates the dynamics of the increase in corn ethanol production over time and the increase in corn acreage for ethanol production over time.

Our analysis makes several contributions to the existing literature examining the impact of corn ethanol production on land use. First, it explains the extent to which the decline in CRP acres between 2007 and 2012 can be attributed directly to corn ethanol. It examines this by focusing on land that could most easily be converted to cropland (that is, expiring CRP acres and cropland pasture) in response to higher returns to land induced directly by corn ethanol production. Second, it also estimates the elasticity of land use change due to higher prices induced by corn ethanol production. It thereby seeks to reconcile the two strands of literature described above that finds substantial conversion of non-cropland to crop production but also an inelastic response of crop acreage to crop prices. Third, the dynamic view of land use change considered here recognizes that the conversion of marginal land to cropland adds to stock of cropland capacity that can be used year after year to support increase ethanol production. This is distinct from the static view of land use change that attributes all of the change in marginal land to a one-time shock in the level of ethanol production. We use BEPAM to examine the total change in cropland acres and marginal land over a period of time in response to the increase in cumulative ethanol produced over that period. Lastly, this paper extends the version of BEPAM developed in Chen et al. (2014a) by considering the potential for expiring CRP acres to exit the program. The previous version of BEPAM assumed that CRP acres remain fixed at the 2007 level of 32 million acres and has been described in detail in Chen et al. (2014b), Hudiburg et al. (2016) and Huang et al. (2013). This implicitly assumed that all CRP acres with expiring contracts automatically re-enrolled in the program. We now extend the BEPAM to consider the potential for expiring CRP acres to exit the program and convert to crop production if it leads to higher net returns to land. Unlike other large scale models, FAPRI, FASOM and GTAP, the estimate of biofuel induced land use changes differ over time and across different categories of marginal land. The representation of land use decisions in BEPAM provides the spatial resolution needed to estimate which types of land (specifically expiring CRP acres) were converted to crop production (Khanna and Zilberman 2012, see review of existing models in Khanna *et al* 2014). Unlike estimates from the FAPRI and GTAP models (Searchinger et al., 2008; Taheripour et al., 2017a,b) which estimate a one-time change in land use due to a one-time shock in corn ethanol production, we show that this estimates varies over time non-linearly with the expansion in corn ethanol production. We also compare our simulated conversion of expiring CRP acres to crop production with the actually observed data on loss of CRP acres over the 2007-2012 period and find a close match; this provides confidence in the ability of the model to explain land use change with and without corn ethanol production.

This paper is organized as follows. In Section II, we describe the modeling framework, followed by a brief description of the key data used in the model in Section III. The results are described in Section IV, followed by the conclusions.

II. Modeling Framework

BEPAM is a dynamic optimization model in which market equilibrium is achieved by maximizing the sum of consumers' and producers' surpluses in the agricultural and transportation sectors subject to various material balance, technological, land availability, and policy constraints over the 2007-2012 period (see Chen et al., 2014). The agricultural sector in the BEPAM includes fifteen conventional crops, eight livestock products, various processed commodities, and co-products from the production of corn ethanol and soybean oil.[3] In the crop and livestock markets, primary crop and livestock commodities are consumed either domestically or traded with the rest of the world (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.

BEPAM considers 295 CRDs in 41 US states as spatial decision units and incorporates the heterogeneity in crop and livestock production across these CRDs, where crop yields and costs of production are specified differently for each CRD and each crop. The model considers five distinct types of land, namely regular cropland, cropland-pasture, land enrolled in CRP, permanent pastureland, and forest pastureland. Unlike regular cropland, land under cropland-pasture is considered to be marginal land because it is intermittently in crop production. CRP acres are also considered marginal land that were previously cropland before they enrolled in the CRP and have the choice of converting back to crop production when the 10-year CRP contract is up for expiration. Permanent pastureland refers to land used primarily for pasture and grazing purposes, such as shrub, sagebrush, and native grasses and may not be suitable for crop production. We obtain data on land in each of these five categories in 2007 from NASS/USDA.

In our simulation model, cropland-pasture acres in each CRD can be converted to crop

[3] Conventional crops include corn, soybeans, wheat, rice, sorghum, oats, barley, cotton, peanuts, potatoes, sugarbeets, sugarcane, tobacco, rye, and corn silage. The primary livestock commodities considered in the model include eggs and milk. The secondary (or processed) crop and livestock commodities consist of vegetable oils from corn, soybeans and peanuts, soybean meal, refined sugar, high-fructose corn syrup, wool and meat products such as beef, pork, turkey, chicken and lamb.

production if the net returns from the conversion to crop production are larger than the costs of conversion in that CRD. We assume that the cost of converting cropland-pasture to crop production is equal to the returns the land would have obtained from producing the least profitable annual crop in the CRD in 2007. This ensures consistency with the underlying assumption of equilibrium in the land market, in which all land with non-negative profits from crop production is utilized for crop production.

For expiring CRP land parcels, we consider two options. They can either re-enroll in the CRP and receive the soil rental payments being offered at that time[4] or they can convert to crop production. The option for re-enrollment implies that the rental payments these acres would receive upon reenrollment serve as the opportunity cost of exiting the program. Thus expiring CRP acres are assumed to exit the program only if the discounted value of net returns from the conversion to crop production are larger than the discounted value of the sum of the soil rental payments they can receive from re-enrollment and the costs of conversion over a ten year rolling horizon (explained below). Expiring acres are assumed to have the same cost of conversion to crop production as cropland pasture. The net returns from converting expiring CRP acres to cropland are endogenously determined and depend on the market prices of crops, crop yields, and production costs of crops. As corn ethanol production increases over time and an increasing amount of corn is diverted from food to fuel production, crop prices and returns to cropland are

[4] Our analysis is based on a simplifying assumption that all marginal land in a CRD (that includes cropland-pasture and existing CRP acres) is homogeneous in its productivity and potential environmental impacts from agricultural production. We are also implicitly assuming that all marginal land is eligible for enrollment in CRP and equally likely to be selected for enrollment in the CRP. Our analysis is not examining the selection and acceptance of expiring CRP acres or other marginal acres in the CRP if they seek enrollment. Since the size of the CRP has declined over time from 36.7 million acres in 2007 to 29.5 million acres in 2012, it implies that new enrollments into the program were smaller than expiring acres that exited the program. We are therefore only focusing on ‘net’ enrollments in the program in each CRD and assume these are drawn from expiring CRP acres in that CRD.

expected to increase. This creates an incentive for conversion of expiring CRP acres and land under cropland-pasture to crop production.

The BEPAM assumes that landowners make long-term land use decisions, which is particularly true for land enrolled in CRP because CRP is usually enrolled through a long-term contract (10-15 years). Specifically, starting with 2007, the model considers a 10-year horizon assuming that landowners make resource allocation plans for the next ten years. We use a 10-year rolling horizon approach to solve the model. This involves first solving the model for the 2007-2016 period. We take the first-year solution values as 'realized', move the horizon one year forward and solve the new problem, and iterate until the problem is solved for year 2012 (thus, the last problem considers the period 2012-2021). The demands for corn ethanol for each year of the 10-year period in each iteration are specified exogenously in accordance with the observed levels of corn ethanol production (the demands for corn ethanol beyond 2012 are specified in accordance with the RFS). Landowners choose the land use that leads to the highest net present value of returns. To prevent unrealistic changes and extreme specialization in land use (since this is a linear programming model), we use the 'historical crop-mix approach' that restricts landowners' planting decisions to a convex combination (weighted average) of historically observed crop specific acreage allocations (see more details in Chen and Önal, 2012; McCarl, 1982). Our analysis endogenously determines crop prices and land allocation to alternative crops under the two alternative scenarios described above. We compare outcomes under these two scenarios to estimate the extent to which the increased demand for biofuels might have led to an increase in crop prices and created incentives for land in CRP and in cropland-pasture to convert to annual crop production.

III. Data

III.1 Calibration of demand and supply functions

We calibrate the domestic demand, export demand and import supply functions for all commodities, using two-year (2006-2007) average prices, consumption, exports and imports of crop and livestock commodities. These domestic/export demands and import supplies are shifted upward over time at exogenously specified rates to capture the increase in demand due to population and income growth. Prices, consumption, exports/imports and elasticities used to calibrate domestic/export demand and import supply curves can be found in Chen et al. (2014a).

III.2 Crop yields and production costs

We incorporate CRD specific data on costs of producing crops and livestock and land availability. We estimate the costs of production in 2007 prices for the fifteen row crops at the county level, which are then aggregated to the CRD level for computational ease. Production costs and yields of individual crop/livestock activities and resource endowments were obtained from various agricultural experiment stations and the USDA/NASS database. We used the historical five-year average (2003-2007) yield per acre for each CRD to calculate average yields of conventional crops for that CRD. The yields of major crops, including corn, soybeans, and wheat, were assumed to increase over time at the trend rate estimated using historical data and described in Chen et al. (2014a).

III.3 Land availability

Data on land availability for different land types for each CRD were obtained from the USDA/NASS. CRD-specific planted acres for the fifteen conventional crops are used to obtain available regular cropland in 2007 (estimated at 304 million acres for the 295 CRDs). Observed availability of cropland-pasture was 37.6 million acres in 2007, while the observed availability of pastureland and forestland pasture was 383 and 26 million acres, respectively. Observed total CRP enrollment in 2007 was 36.7 million acres.

We obtained county-level CRP contract data from the Farm Service Agency of the US Department of Agriculture. The dataset included CRP contracts for 2,332 counties in 36 states from 1996 to 2012 and the average rental rate at each signup (i.e. a specified enrollment period) as well as the total CRP acres enrolled during each signup in each county (including continuous and general enrollment). The average rental rate is the area-weighted average of rental payments for CRP land parcels in continuous and general enrollment. We aggregated the county-level CRP data to the CRD level for ease of numerical analysis. We computed the amount of CRD-level expiring CRP acres each year over the 2007-2012 period and CRD-specific average soil rental payments received by these enrolled acres. We assumed that the returns that expiring CRP acres could earn upon reenrollment would be equal to the soil rental payments offered to newly enrolling CRP acres during the sign-ups over the 2007-2012 period.

III.4 Productivity of marginal land

Similar to any large-scale economic model, BEPAM relies on numerous parameter and functional form assumptions. These assumptions are based on the literature and documented in Chen et al. (2014). One particular assumption for which there is no publically available information at the CRD level is the productivity of land enrolled in CRP and the returns these acres would earn if they were converted to crop production. This productivity is expected to vary across CRDs and affect the incentives for expiring CRP acres to convert to crop production. In the absence of data, we consider several alternative assumptions about this productivity.

We first allow for the ratio of the productivity of CRP acres to regular cropland acres to differ across CRDs and assume that this ratio is the same as the ratio of the rental payment for a

CRP acre to the average dryland cash rents in that district. We obtained county-level dryland cash rents from the USDA-NASS Quick Stats database and converted the county-level data into CRD-specific dryland cash rents. This estimated crop productivity ratio varies by CRD and averages 36.8% across CRDs. We found that, with this productivity assumption our model provided the closest fit to the observed data on reduction in CRP acres (see discussion below) Thus, we selected this productivity assumption as our benchmark productivity assumption. We also follow Hertel et al. (2010) and assume that the productivity of CRP and cropland-pasture is uniformly 33%, 50% or 100% of that of regular cropland.

IV. Results

IV.1 Model Validation

We compared the percentage deviations between model-simulated and observed CRP acres under various assumptions about productivity of CRP and cropland-pasture noted above in each of the years 2007-2012 (see Figure S1 in the Supporting Information). We obtained simulated CRP acres over the 2007-2012 period by running BEPAM with the observed levels of corn ethanol production that increased from 6.5 billion gallons in 2007 to 13.2 billion gallons in 2012 as a constraint.

We found that, by raising food commodity prices, corn ethanol production created incentives for expiring CRP acres to leave the program and convert to cropland. Observed net acres in CRP after accounting for expirations and new enrollments declined from 36.7 million acres in 2007 to 29.5 million acres in 2012. In comparison, our model simulated enrollment in CRP declined from 35.6 million acres in 2007 to 28.3 million acres in 2012. Figure 1(a) shows the annual percentage deviations between simulated and observed CRP acres under the benchmark productivity assumption. Compared to observed CRP acres during the 2007-2012 period, percentage deviations ranged between (-) 4.2% and (+) 1.7%. In the aggregate, the total observed decline in CRP acres between 2007 and 2012 was 7.23 million acres. Our simulation estimated this reduction to be 7.37 million acres and was therefore in close agreement with the observed data.

Figure 1(b) presents the results obtained with the assumption that the ratio of the productivity of marginal land to regular cropland acres is 33%. Deviations between simulated and observed CRP acres for the 2007-2012 period ranged between (-)3.2% and (+)1.5%, which are very similar to those obtained in the benchmark case. The total simulated decline in CRP acres between 2007 and 2012 was 7.07 million acres with this productivity assumption (Table S1 in the Supporting Information), which was also close to the observed decline in CRP acres during this period (7.23 million acres).

By testing the ability of the model to provide outcomes close to those observed in reality and then keeping all assumptions the same in the counterfactual Scenario 1 "Ethanol fixed at the 2007 level" and focusing on the deviations in outcomes between Scenarios 1 and 2, we reduce the effects of uncertainty about these assumptions that affect both scenarios equally on the estimate of this deviation as much as possible. Since the counterfactual scenario, is unobserved, we relied on this validated model to generate outcomes in that scenario by keeping all other assumptions unchanged. We, thereby, isolated the extent to which land use change could be attributed to increased ethanol production during the 2007-2012 period. We discuss the effects of corn ethanol production with the benchmark productivity assumption below, and examine the sensitivity of the model to a number of assumptions as described in section IV.5.

IV.2 Conversion of Marginal Land to Crop Production due to Corn Ethanol

We now present results that compare outcomes under the two simulated scenarios, namely Scenario 1 “Ethanol fixed at the 2007 level” and Scenario 2 “Ethanol is at the observed levels with RFS”, for the 2008-2012 period (table 1). In Scenario 2, the simulated annual reduction in CRP acres ranged from 0.68 million acres in 2008 to 1.97 million acres in 2012; the cumulative reduction in CRP acres by 2012 was 7.37 million acres. This was larger than the estimated total reduction of 6.39 million CRP acres that would have occurred in Scenario 1 over 2008 to 2012. This implies that the reduction of 0.97 million acres in CRP (that is 13% of the decline in CRP acres) during the 2008-2012 period could be attributed to increased corn ethanol production.

In addition to CRP acres, land under cropland-pasture also moved in and out of crop production on an annual basis in response to the expected returns to the land. Table 1 shows the amount of cropland-pasture converted to crop production in a given year (2008-2012) relative to the level in 2007. This amount varied from year to year. Note that the changes in cropland-pasture acres shown here are relative to the level in 2007; this is unlike the conversion of CRP acres which were the annual changes relative to the previous year and could be cumulated over time. Annual changes in cropland-pasture are therefore not additive over time.

We estimate that the amount of land under cropland-pasture converted to crop production ranged between 12.4-12.9 million acres during this period in Scenario 2; the corresponding value in Scenario 1 would have been 10.3-11.5 million acres over the same period. By 2012, the total reduction in marginal land (including CRP acres and cropland-pasture) that could be attributed to corn ethanol was 3.15 million acres, which included 0.97 million acres of CRP and 2.18 million acres of cropland-pasture. On an annual basis, the conversion of marginal land (from CRP and cropland-pasture) due to biofuels increased over time from 9.4% to 17.7% between 2008 and 2012 under the benchmark productivity assumption (see last column of Table 1).

We converted our estimate of total changes in marginal land to a per gallon estimate. We mimicked the static impact of a biofuel production shock by calculating the change in marginal land per unit of the annual increase in corn ethanol production in each year (2008-2012). As shown in figure 2a, this ranged between 338 and 453 acres per million gallons. However, it would be incorrect to attribute all of the reduction in marginal lands in a given year to increased corn ethanol production in that year. Marginal land once converted to crop production, increases the long-term capacity to produce corn ethanol and thus gallons produced per acre of land converted extend into the future. We incorporated this capacity effect by cumulating the changes in total marginal land that could be attributed to additional corn ethanol since 2007 (obtained from Table 1) and comparing it to the cumulative production of ethanol since 2007. Because the cumulative production of corn ethanol increased more rapidly than the cumulative conversion of marginal land to crop production that could be attributed to corn ethanol, we find that the cumulative change in acres/cumulative million gallons declined over time. Figure 2a shows that it ranged from 453 acres per million gallons in 2008 to 112 acres per million gallons in 2012. With the 33% productivity assumption, the estimates of the changes in marginal land due to corn ethanol over the 2008-2012 period ranged between 562 and 162 acres per million gallons of corn ethanol (see figure 2b).

We estimate that the doubling of corn ethanol production led to an increase in total cropland used for crop production by 1% by 2012 relative to the counter-factual level in 2012 (Table 2). The production of the additional 6.7 billion gallons of ethanol in 2012 was accompanied by a 15% increase in land under corn. Despite the increase in total cropland, there was a net reduction in corn acres to meet food/feed needs and a reduction in acres used to produce other crops (all by 4%). Relative to Scenario 1 ("Ethanol fixed at the 2007 level"), the increase in demand for corn for ethanol raised corn prices by 19% and soybean prices by 14% (figure 3), while increasing cropland rent by 15% in 2012. We found that these changes in crop prices are similar to the estimates reported in Searchinger et al. (2008) and USEPA (2010).

This increase in land rent expanded total land used for crop production over 2007-2012 by 1% relative to the level in Scenario 1 (Table 2), implying a land use change elasticity of 0.066 (=1.0%/15%). Our finding that land use is relatively price inelastic is similar to the findings by Barr et al.(2011) and Swinton et al.(2011), although our estimates are not directly comparable with those studies. We are comparing the change in cropland acres and land rents due to biofuels at a point in time using a 'with' and a 'without' additional ethanol production comparison, while they are comparing the change in land use and land rents between two points in time using a 'before' and 'after' approach. In a 'before' and 'after' comparison of land use at two points in time, other factors could have changed over time as well, in addition to the level of corn ethanol production. As a result, they are not isolating the extent to which the increase in cropland acres was due to corn ethanol production alone, while keeping all other factors unchanged.

Our simulated results also show that the spatial distribution of the converted CRP land was concentrated in states having comparative advantage in producing corn, such as in Midwestern states including Iowa and Illinois, and Plain states including Kansas, N. Dakota, Kentucky, Texas, and Nebraska. Together these states accounted for more than 93% of the total CRP acres and 44.5% of the cropland-pasture converted to cropland.

IV.3 Expansion of Crop Acreage on Existing Cropland vs Marginal Land

Our simulations show that the increase in demand for corn led to a net expansion of corn acreage in 2012 by 12.4 million acres, after considering the decline in demand for corn for food/feed due to higher corn prices and the potential to use the corn ethanol by-product (Distillers Dried Grains Solubles (DDGS)) as livestock feed (Table 2). We found that this expansion of corn acreage occurred entirely through substitution of land from other crops on land that was already under crop production in 2007. Land was converted from other crops, such as soybeans, wheat, cotton, rice, sorghum, and barley to corn production. Cropland under soybeans and wheat was lower by 6.3 and 1.0 million acres, respectively, in 2012. Similarly, total cropland allocated to other annual crops declined by 1.9 million acres in 2012 relative to the counterfactual "Ethanol fixed at the 2007 level" scenario. The conversion of marginal land to crop production was largely observed for other crops. As a result, total acreage under other crops did not decline as much. Because of the conversion of 7.3 million acres of marginal land (from CRP and cropland-pasture) to these other crops; the net acreage under other crops decreased by only 9.2 million acres.

Figure 4 shows the regional distribution of land use changes under corn, soybeans, wheat and alfalfa in 2012 that could be attributed to the additional corn ethanol production, as determined by comparing outcomes under Scenario 2 ("Ethanol is at the observed levels with RFS") with those obtained under Scenario 1 ("Ethanol fixed at the 2007 level"). Much of the expansion in corn acres occurred in the Midwest followed by the Great Plains and on land already under crop production as 6.0 million acres of soybean were converted to corn (see figures 4a and 4b). While cropland acres under wheat declined by 2.3 million acres, 1.4 million acres of marginal land in Midwestern, Southern, Plain, Atlantic, and Western states were converted to wheat, leading to a net decline of 1.0 million acres of wheat acres (figure 4c). Corn ethanol production also led to a conversion of 2.6 million acres of marginal land to alfalfa in the Midwest and Great Plains areas (figure 4d). We also found that, under the 33% productivity assumption the regional distribution of land under corn, soybeans, wheat and alfalfa in 2012 was similar to our benchmark results (see figure S2 in the Supporting Information).

IV.4 Implications of Biofuels for the Costs of Preventing Exit from CRP

A key economic implication of higher prices induced by the increased production of corn ethanol is that it raises the land rental payments that need to be offered to CRP acres to prevent expiring acres from exiting the program. We used our findings on higher crop prices induced by corn ethanol production to assess the extent to which rental payments should have been raised over the 2007-2012 period to induce reenrollment by expiring acres in the CRP for a 10-year period. We find that the net present value of rental payments needed to prevent expiring CRP acres from exiting the program increased by $1.1 billion as a result of the higher crop prices induced by corn ethanol. Under Scenario 1 (“Ethanol fixed at the 2007 level”), the net present value of land rental payments needed to prevent expiring CRP acres from leaving the program for crop production is $8.7 billion. The production of corn ethanol increased these costs of maintaining CRP at 2007 levels by 12.4% to $9.8 billion relative to the counter-factual scenario (Table 2).

IV. 5 Sensitivity Analysis

We examined the sensitivity of our results to alternative values of several parameters by varying the value of one parameter at a time and estimating its effect on several key variables in twelve scenarios (Appendix B in the Supporting Information has detailed description). We considered alternative assumptions about the productivity of marginal land (CRP and cropland-pasture), trend rates of growth of crop yields, rental payments that expiring CRP acres would earn if they re-enrolled in the program, conversion costs of marginal land, and availability of cropland-pasture. We examined the effects of these assumption on several key variables including total US cropland and corn price in 2012, the cumulative reduction in marginal land over the 2007-2012 period, and the discounted value of the total CRP maintenance cost over the 2007-2012 period. For each of these variables, we first computed the percentage changes in value under Scenario 2 ("Ethanol is at the observed levels with RFS") relative to Scenario 1 ("Ethanol fixed at the 2007 level") under the benchmark assumptions and under each of the alternative parameter assumptions.[5] We then computed the differences in these percentage changes for the four outcome variables under each of these scenarios, relative to those obtained under the benchmark case.[6] Figure 5 presents these differences.

Figure 5 shows that the deviations in estimated percentage increases in total US cropland due to the additional corn ethanol production across the twelve scenarios and our benchmark scenario are negligible (see rows 'd' of Table S2 in the Supporting Information). The impacts of corn ethanol production on corn price are generally within ± 2% of the estimate obtained in the benchmark case.[7] Estimates of the conversion of marginal land (CRP and cropland-pasture) due to corn ethanol over the 2007-2012 period were within ± 5% of the estimate obtained in the

[5] These percentage changes are reported in rows 'c' of table S2(a) and (b) in the Supporting Information.
[6] See rows 'd' of table S2 (a) and (b) in the Supporting Information.
[7] There are two exceptions in Scenarios (3) and (12). In the two scenarios, the estimated impact on corn price due to corn ethanol production is 5.0-6.5% larger than our benchmark estimate. This is expected, because with zero price elasticity, corn yield would be lower than that in the benchmark scenario, which in turn leads to higher corn price.

benchmark case.[8] We found that the estimates of the total maintenance costs of CRP during the 2007-2012 period due to corn ethanol under the various scenarios considered here were within ± 3% of the estimate obtained in the benchmark case.

V. Conclusions and Policy Implications

This paper examined the extent to which the conversion of marginal land from the CRP and from cropland-pasture could be attributed to the increase in corn ethanol production over the 2007-2012 period in the US. We developed an economic model to project crop prices and land use under two alternative scenarios that differ in the level of corn ethanol produced. We compare outcomes from the two scenarios to determine the impact of corn ethanol production on the land use. We found that the expansion of corn ethanol by 6.7 billion gallons between 2007 and 2012 led to the conversion of 3.2 million acres of land previously in CRP and cropland-pasture to crop production. This included the conversion of about 1 million acres of CRP acres (or about 16% of the decline in CRP acres) that could be attributed to the increase in corn ethanol over the 2007-2012 period. The reduction of 3.2 million acres of marginal land accounted for about 13% of the total reduction in marginal land over the 2007-2012 period. While corn ethanol was responsible for a substantive amount of change in marginal land as noted by Wright et al. (2017), it is important to note that this expansion of cropland between 2007-2012 was by only 1% relative to the level of cropland acres with the 2007 level of corn ethanol Our findings of the low overall

[8] One exception is Scenario (1) that assumed the ratio of productivity of CRP acres was uniformly 33% of cropland, with the estimated impact being 14% larger than the benchmark estimate. We found that, in this scenario, the amounts of marginal land converted to crop production under both scenarios were smaller than the corresponding estimates in the benchmark case. These were expected, given the productivity assumption. Because the denominator used to compute the percentage change in the conversion of marginal land in this scenario was smaller, that led to larger estimated impact of corn ethanol on the conversion of marginal land as compared to the benchmark estimate. In absolute terms, the reduction in marginal land that can be attributed to corn ethanol ranged between 2.8 and 4.6 million acres across the various parametric assumptions considered here.

responsiveness of aggregate crop acreage in the US to changes in biofuel-induced crop price increases and a low elasticity of land use change to land rents of 0.066 are similar to the observations by Barr et al. (2011) and Swinton et al. (2011). These findings imply that marginal land is fairly price-inelastic and thus increased demand for corn for ethanol was largely met by substitution of land from other crops to corn. There was a net reduction in acres used to produce other crops (by 4%) as land under soybeans, wheat and other crops was converted to corn.

Of the total expansion in crop production on marginal land, about 93% occurred in the major corn producing states in the Midwest and Great Plains. The conversion of land from other crops to corn in these regions led to the expansion of those crops on marginal land. We also find that corn ethanol production raised price of corn by 15%-27% and of soybean by 6%-17% over the 2007-2012 period. As a result, corn ethanol production increased the rental payments that would need to be offered to expiring CRP acres to prevent them from exiting the program. The potential cost of preventing exit from CRP over this period was 12.4% higher than in the counter-factual scenario.

The features of the modeling framework used here result in changes in marginal land evolving over time depending on endogenously determined CRD specific returns to land, historical allocation of cropland to various food and feed crops, and projections of demand for food and feed and crop yields. This approach differs from that used in existing general equilibrium and multi-market partial equilibrium models that assume a constant elasticity of land supply or transformation of land from one use to another that does not vary over space or time (Khanna and Crago 2012, Khanna and Zilberman 2012). By showing that observed data on changes in CRP acres were close to model-simulated outcomes, our analysis provides confidence in estimates of the extent to which land use changes could be attributed to corn ethanol production. Our analysis, however, relies on several simplifying assumptions, including those about the productivity of CRP and other marginal acres, the response of management practices to changes in crop prices, the rental payments offered to expiring CRP acres for re-enrollment in the program. The availability of more data as well as a more detailed exploration of the sensitivity of the model to multiple sources of uncertainty could improve the accuracy of the assessment and of the possible range for the estimated impacts of corn ethanol production. We leave that for future research.

Our analysis has several policy implications. First, it shows the importance of considering the unintended effects of policy and their costs when making policy choices. In the case of biofuel mandates, the indirect effect on food crop prices and the returns to cropland led to declining incentives for enrollment/re-enrollment in CRP at current soil rental rates. This implies that the rental payments for CRP would need to increase over time as biofuel production increases in order to maintain CRP acreage and the environmental benefits it provides. Second, we show that the indirect effects of corn ethanol production on land use varied over time as biofuel production increased. Most studies estimated a single value of indirect land use change per gallon of biofuel which is assumed to be constant over time even as biofuel production increases (Hertel *et al* 2010, Searchinger *et al* 2008, USEPA 2010, Taheripour and Tyner 2013). Regulatory agencies, such as the USEPA and the California Air Resources Board, have used the estimate of the indirect land use change due to biofuels to estimate its implications for greenhouse gas emissions released due to the conversion of the land. This is then used to determine compliance of a biofuel with the Renewable Fuel Standard and the California Low Carbon Fuel Standard (EPA, 2010; CARB, 2014). Our analysis shows the fallacy of treating this value as fixed over time as biofuel production increases.

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Table 1. Effects of corn ethanol production on marginal land conversion (million acres)[1]

	Scenario 1: Ethanol fixed at the 2007 level		Scenario 2: Ethanol is at the observed levels with RFS			
Year (t)	Conversion of CRP to cropland in year t relative to year t-1 (a)	Conversion of cropland-pasture to cropland in year t relative to the level in 2007 (b)	Conversion of CRP to cropland in year t relative to year t-1 (c)	Conversion of cropland-pasture to cropland in year t relative to the level in 2007 (d)	Total reduction in marginal land due to corn ethanol in year t (e=c+d-a-b)	% change in marginal land due to corn ethanol (f=e/(c+d))
2008	0.64	11.54	0.68	12.76	1.26	9.4
2009	1.40	10.99	1.49	12.69	1.80	12.7
2010	1.36	10.73	1.65	12.91	2.46	16.9
2011	1.38	10.45	1.57	12.77	2.50	17.5
2012	1.61	10.25	1.97	12.44	2.54	17.7
Cumulative reduction in CRP acres (2008-2012)[2]	6.39		7.37			
Total conversion of marginal land (CRP and cropland-pasture) in 2012 relative to 2007 [3]	16.65		19.80		3.15	

Notes: [1] Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with the RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint. Columns (a) and (c) represent the change in CRP acres in year t relative to year t-1. Columns (b) and (d) represent the conversion of land in cropland-pasture to crop production in a given year relative to the base year 2007. The amount of conversion of cropland-pasture to cropland varies from year to year depending on the profitability of crop production in each year. Column (e) represents the addition to cropland in year (t) that can be attributed to the additional corn ethanol production during the 2008-2012 period.

[2] Numbers in this row denote the sum of converted CRP acres (columns (a) and (c)) from 2008 to 2012.

[3] Numbers in this row denote the sum of the total reduction in CRP acres by 2012 and the amount of cropland-pasture land converted in 2012 under Scenarios 1 and 2, respectively.

Table 2. Effects of corn ethanol production on land use and land rent in 2012

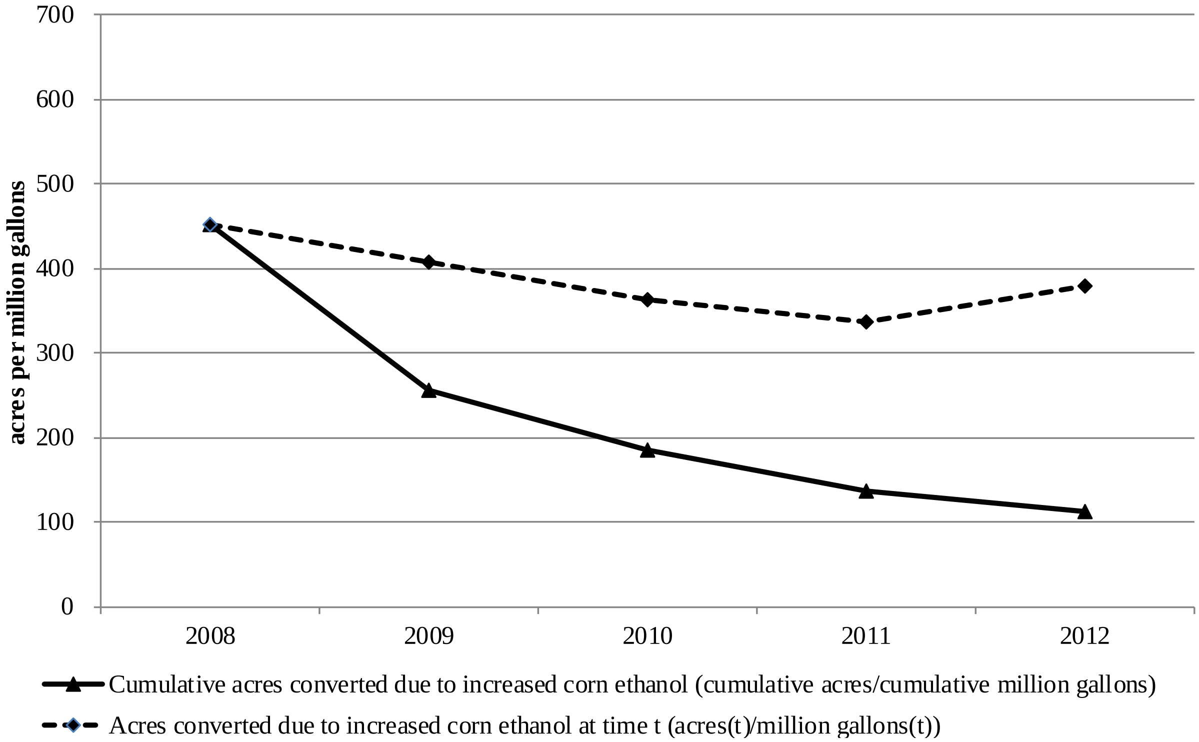
Scenario[1]	Scenario 1: Ethanol fixed at the 2007 level	Scenario 2: Ethanol is at the observed levels with RFS	Change[2]
	(1)	(2)	(3)
Total cropland (million acres)	322.1	325.3	3.2 (1.0%)
Regular cropland in 2007	*304.1*	*304.1*	*0.0*
Conversion of cropland-pasture in 2012	*10.3*	*12.4*	*2.2*
Conversion of CRP land by 2012	*6.4*	*7.4*	*1.0*
Land under corn (million acres)	83.4	95.7	12.4
Corn for food (million acres)	68.4	65.6	-2.9
Corn for ethanol (million acres)	14.9	30.2	15.2
Other food/feed crops (million acres)	238.8	229.5	-9.2
Land rent ($/acre)	342.7	393.8	51.1 (14.9%)
Land use change elasticity		6.6%	
Total CRP maintenance costs ($ billion)	8.7	9.8	1.1 (12.4%)

Notes: [1] Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with the RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

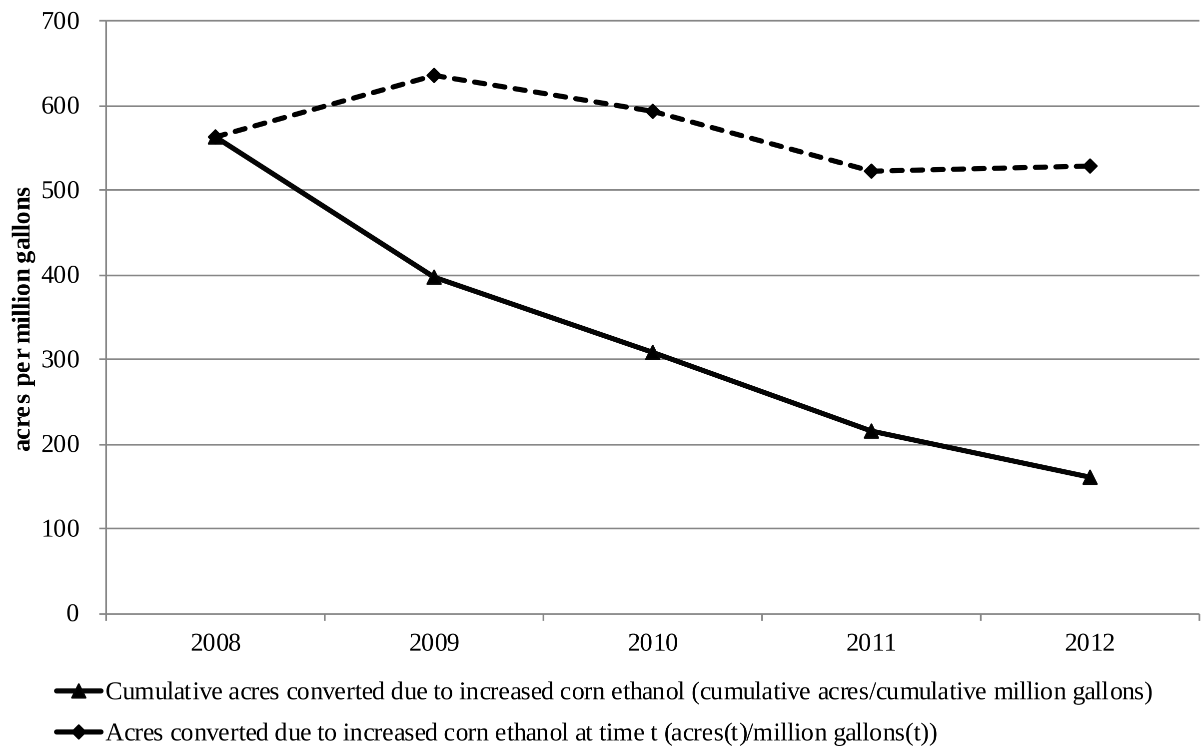
[2] This column shows the differences in values in columns (1) and (2). Figures in parenthesis are the percentage changes in Scenario 2 relative to Scenario 1.

(a) Benchmark productivity assumption (b) 33% productivity assumption

Figure 1. Percentage deviations in observed data and simulated CRP acres (million acres) in the 'Ethanol is at Observed Levels with RFS Scenario'



(a) Benchmark productivity assumption



(b) Assumed 33% productivity assumption

Figure 2. CRP acres and cropland-pasture acres converted due to increased corn ethanol production

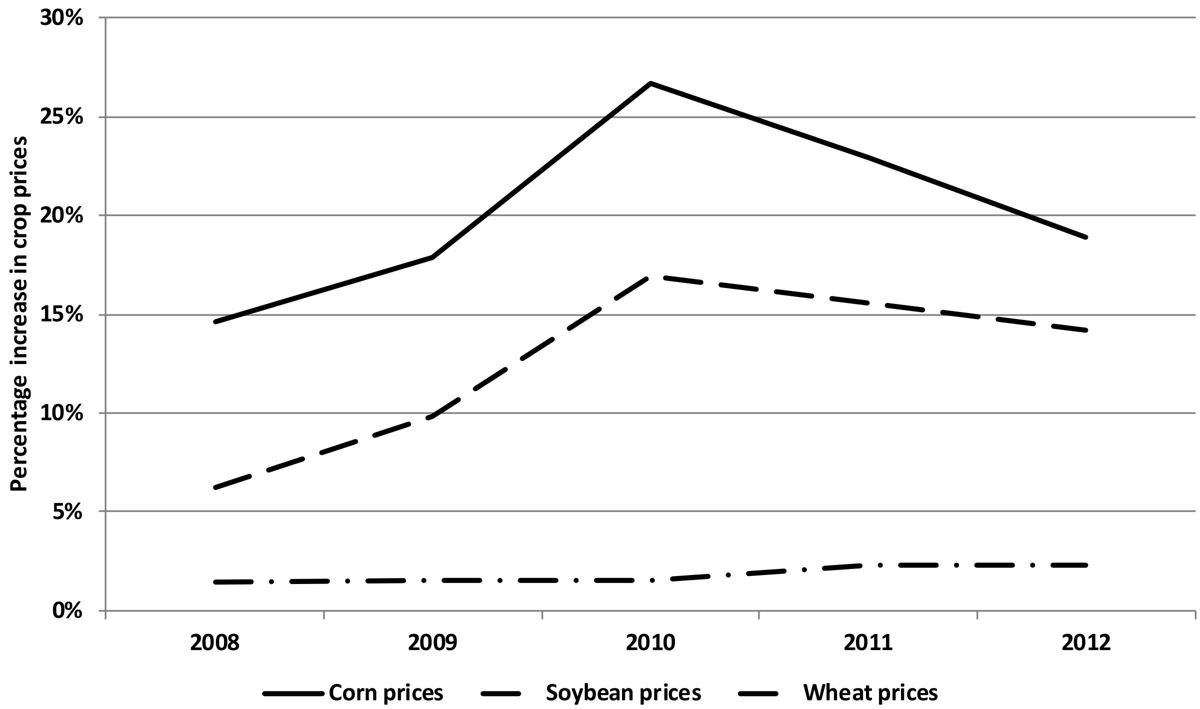


Figure 3. Impact of corn ethanol production on crop prices

Notes: Percentage increases in crop prices under Scenario 2 ("Ethanol is at the observed levels with RFS") are computed relative to crop prices under Scenario 1 ("Ethanol fixed at the 2007 level"). Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with the RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

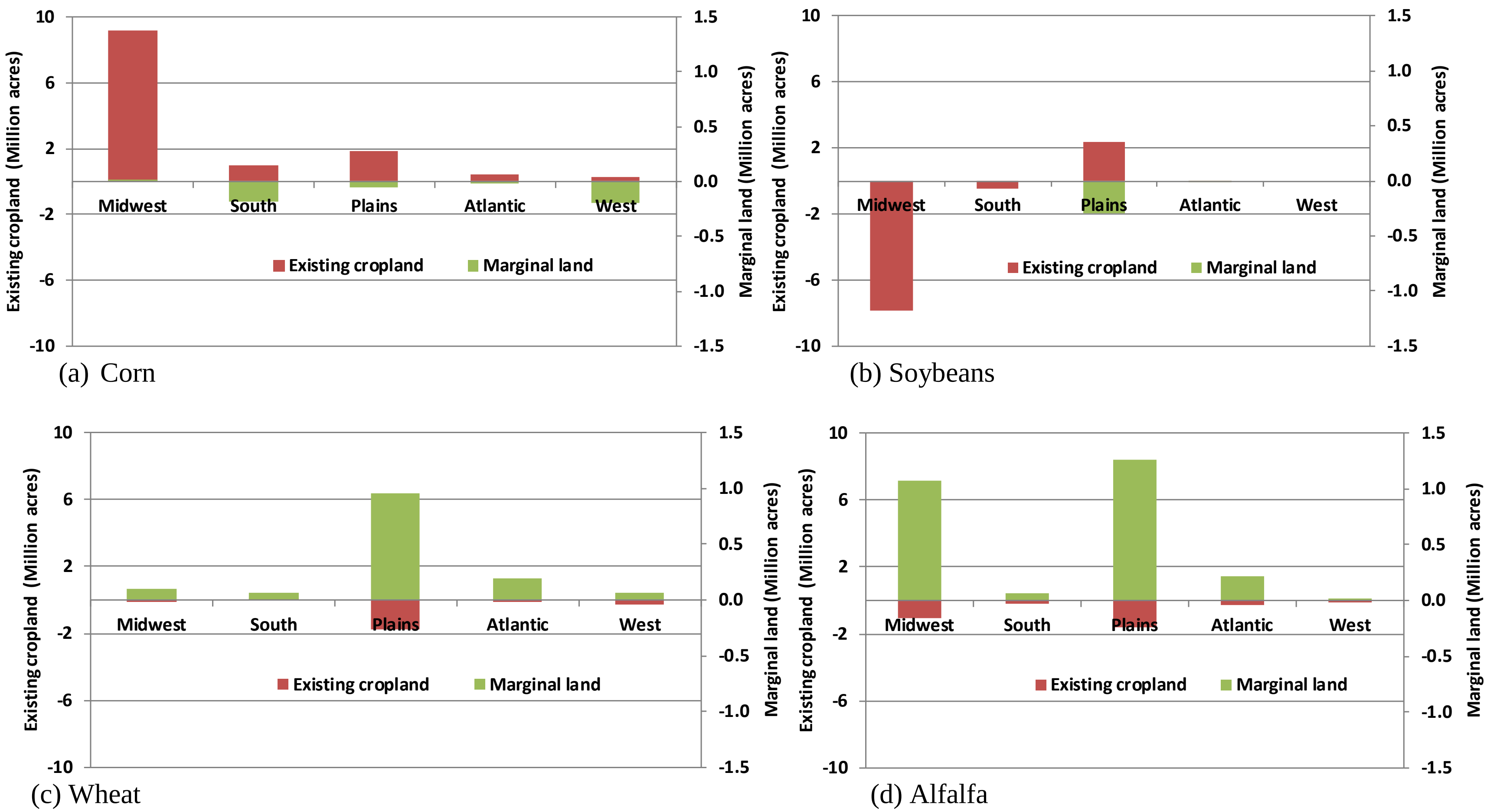


Figure 4. Regional distribution of land use changes due to corn ethanol production (million acres)

Notes: red bars denote the differences in amounts of regular cropland used for crop production between Scenario 2 (“Ethanol is at the observed levels with RFS”) and Scenario 1 (“Ethanol fixed at the 2007 level”), while green bars denote the corresponding differences in marginal land. Positive values indicate an increase in land being used due to corn ethanol for a particular crop, while negative values indicate a reduction in land being used for a particular crop due to corn ethanol. Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with the RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

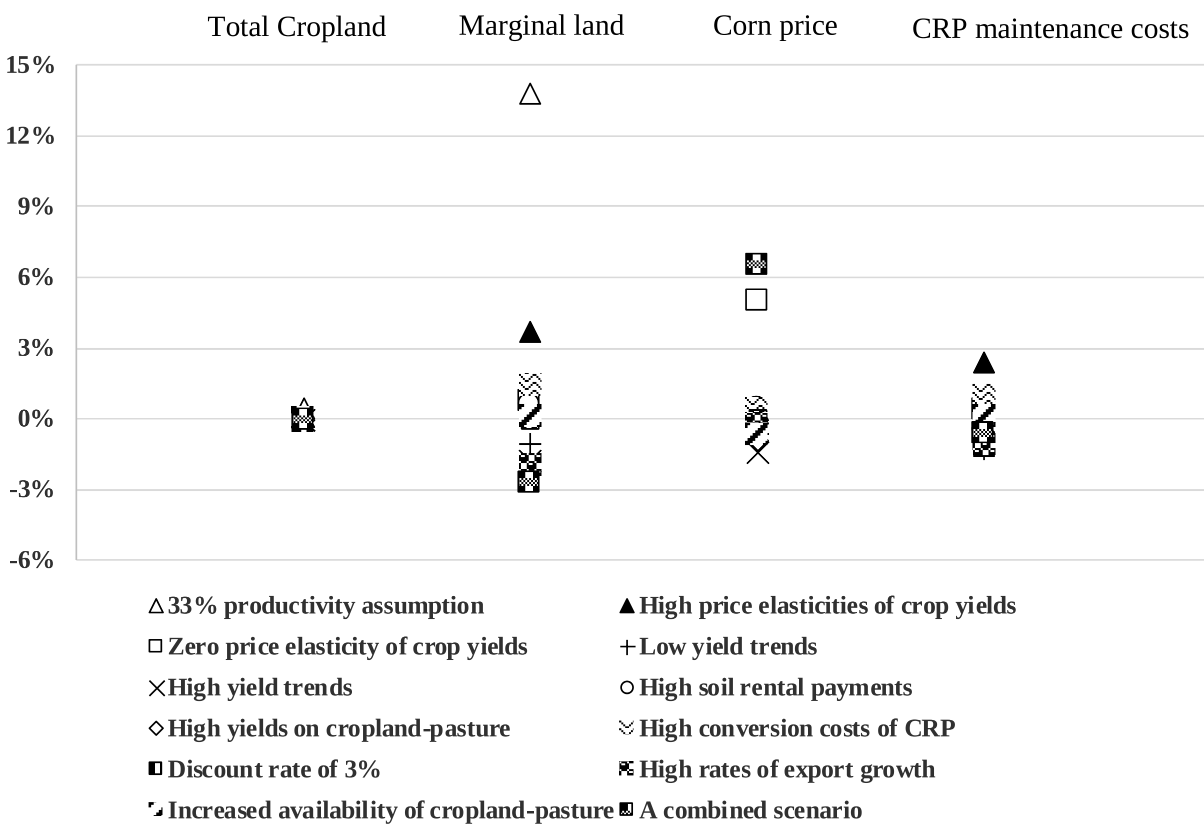


Figure 5. Sensitivity analysis: Deviation in the Percentage Change due to Biofuels Under the Benchmark Parameters and Under each Alternative Parametric Assumption
Notes: A value close to zero indicates that model outcomes under the benchmark assumptions were close to those under the alternative parametric assumption.

Effect of Corn Ethanol Production on Conservation Reserve Program Acres in the US

SUPPORTING INFORMATION

Appendix A: Tables and Figures

Table S1. Effects of corn ethanol production on marginal land conversion (million acres): assumed 33% productivity of CRP[1]

	Scenario 1: Ethanol fixed at the 2007 level		Scenario 2: Ethanol at the observed levels with RFS			
Year (t)	Conversion of CRP to cropland in year t relative to year t-1 (a)	Conversion of cropland-pasture to cropland in year t relative to the level in 2007 (b)	Conversion of CRP to cropland in year t relative to year t-1 (c)	Conversion of cropland-pasture to cropland in year t relative to the level in 2007 (d)	Total reduction in marginal land due to corn ethanol in year t (e=c+d-a-b)	% change in marginal land due to corn ethanol (f=e/(c+d))
2008	0.59	9.87	0.64	11.39	1.57	13.0
2009	1.33	8.89	1.56	11.47	2.81	21.5
2010	1.25	8.64	1.70	12.22	4.03	28.9
2011	1.11	8.48	1.40	12.06	3.87	28.8
2012	1.18	8.44	1.78	11.37	3.54	26.9
Cumulative reduction in CRP acres (2008-2012)[2]	5.45		7.07			
Total conversion of marginal land (CRP and cropland-pasture) in 2012 relative to 2007 [3]	13.9		18.5		4.6	

Notes: [1] Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint. Columns (a) and (c) represent the change in CRP acres in year t relative to year t-1. Columns (b) and (d) represent the conversion of land in cropland-pasture to crop production in a given year relative to the base year 2007. The amount of conversion of cropland-pasture to cropland varies from year to year depending on the profitability of crop production in each year. Column (e) represents the addition to cropland in year (t) that can be attributed to the additional corn ethanol production during the 2008-2012 period.

[2] Numbers in this row denote the sum of converted CRP acres (columns (a) and (c)) from 2008 to 2012.

[3] Numbers in this row denote the sum of the total reduction in CRP acres by 2012 and the amount of cropland-pasture land converted in 2012 under Scenarios 1 and 2, respectively.

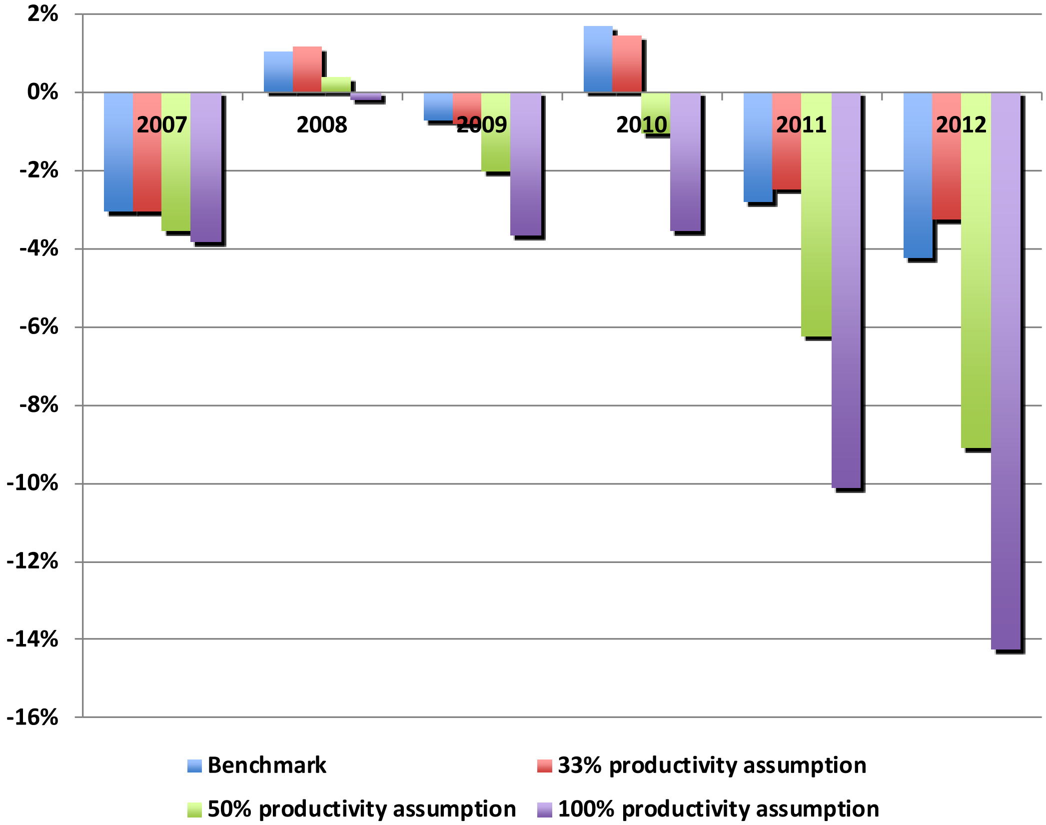
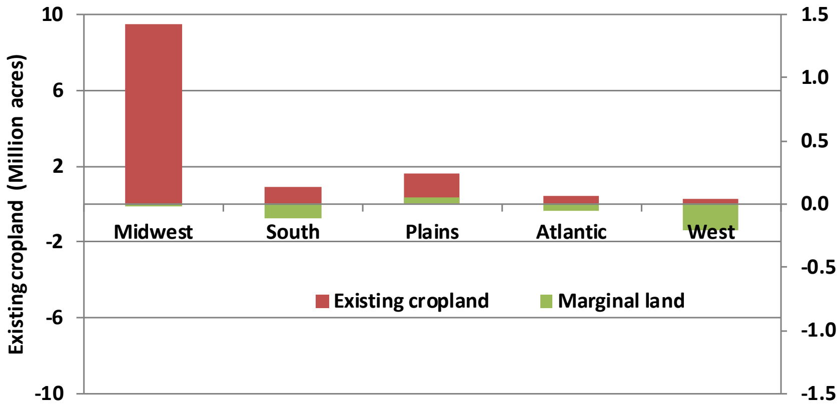
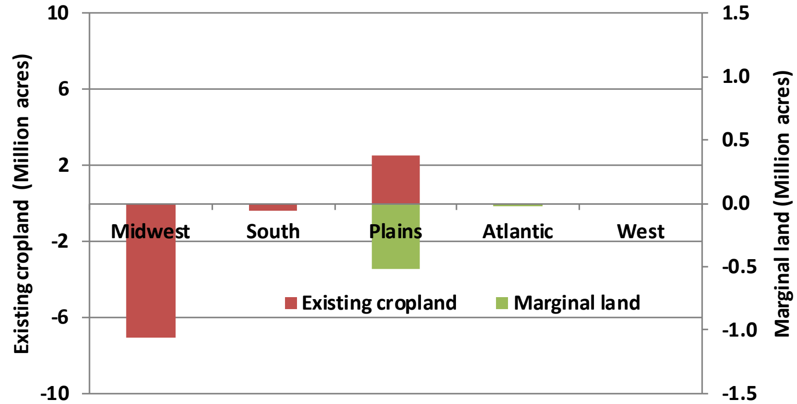


Figure S1. Percentage deviations between simulated and observed data on CRP acres under alternative assumptions about productivity of marginal land in each of the years 2007-2012

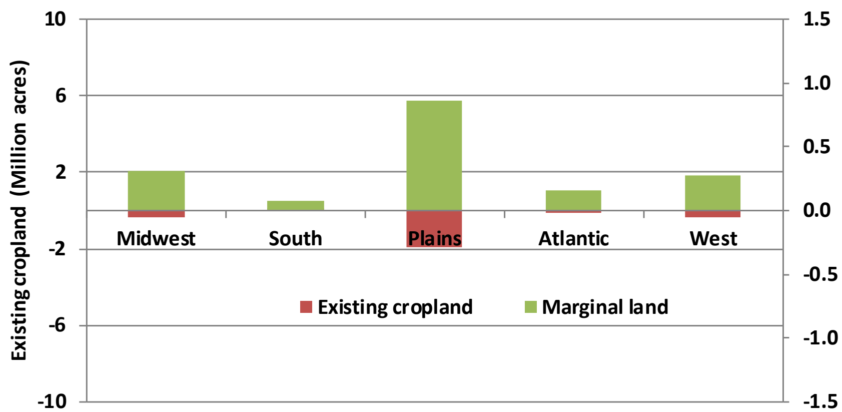
Notes: In addition to the benchmark productivity assumption, we considered three alternative assumptions about productivity of marginal land, namely that crop yields are 33%, 50%, and 100% of that of average cropland in the CRD.



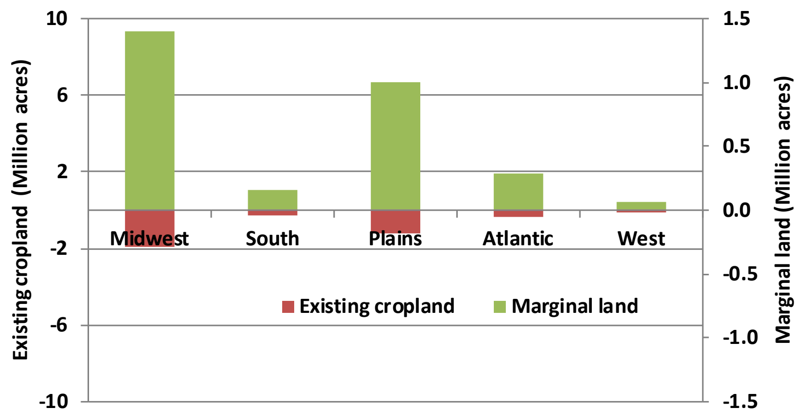
(a) Corn



(b) Soybeans



(c) Wheat



(d) Alfalfa

Figure S2. Regional distribution of land use changes due to corn ethanol production (million acres): assumed 33% productivity of CRP
Notes: red bars denote the differences in amounts of regular cropland used for crop production between Scenario 2 ("Ethanol at the observed levels with RFS") and Scenario 1 ("Ethanol fixed at the 2007 level"), while green bars denote the corresponding differences in marginal land. Positive values indicate an increase in land being used due to corn ethanol for a particular crop, while negative values indicate a reduction in land being used for a particular crop due to corn ethanol. Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

Appendix B: Scenarios for sensitivity analysis

In Scenario (1), we first examined the sensitivity of model outcomes to the assumption of the ratio of the productivity of CRP acres being uniformly 33%. We then examined the robustness of our findings to variations in the price elasticities of crop yields (corn, soybean, and wheat) and the trend rates of yield growth in Scenarios (2)-(5). Miao et al. (2016) provide empirical evidence that corn yields are price-elastic: the higher the price elasticity, the larger the effect of biofuel induced crop prices on yield per acre. Our benchmark analysis assumed a price elasticity of corn yield of 0.23.[9] We examined the extent to which alternative assumptions about this elasticity affects the impact of corn ethanol production on land use and crop prices. Specifically, in Scenario (2), we assumed the elasticity of corn yields to corn prices to be 100% higher than our benchmark assumption. In Scenario (3), we assumed that the value of this elasticity is zero. We also examined the sensitivity of our results to alternative assumptions about the trend rates of growth of crop yields. In the benchmark, we assume that the rates of growth of yields for corn, soybean, and wheat are 2.1, 0.2 and 0.6 bushels per year, respectively. In Scenarios (4) and (5), we assumed that these trend rates of crop yields were 50% higher and lower, respectively, than that in our benchmark case.

We then examined the sensitivity of our results to alternative assumptions about the returns that marginal land (CRP and cropland-pasture) would earn if they were converted to crop production in Scenarios (6)-(8). Specifically, in Scenario (6), we assumed that the returns that expiring CRP acres could earn upon reenrollment would be 10% higher than the payments assumed in the benchmark scenario, which was based on the observed soil rental payments being offered during the 2007-2012 period. In Scenario (7), we considered the possibility that crop

[9] Price elasticities of yields for soybean and wheat are assumed to be zero.

yields on cropland-pasture could be 10% higher than that on CRP acres. In Scenario (8), we assumed conversion costs of CRP acres to be 10% higher than the costs of converting cropland-pasture to crop production.

In Scenario (9), we considered a discount rate of 3%, which was assumed to be 4% in the benchmark scenario, to examine whether our results are sensitive to this assumption. We also examined sensitivity to the rate of growth in demand for agricultural commodity exports since this will affect the extent to which corn ethanol production will impact world market crop prices. In Scenario (10), we doubled the rates of the shifts in export demand curves of agricultural products. Furthermore, we examined sensitivity to the assumption that only CRP and cropland pasture acres could convert to crop production. Acres under other land uses, such as permanent pastureland, were assumed to be fixed in our benchmark case. In Scenario (11), we examined the sensitivity of our results to that assumption by assuming that the amount of cropland-pasture available for conversion to crop production is 10% higher than the observed availability of cropland-pasture in 2007. Lastly, in Scenario (12), we considered the possibility that several parameter changes described above could coexist. Specifically, this scenario simultaneously considered the assumptions made in Scenario (3) with zero price elasticity of corn yields, Scenario (7) with high crop yields on cropland-pasture, Scenario (8) with high conversion costs of CRP acres, and Scenario (10) with doubled rates of the shifts in export demand curves of agricultural products. We selected these scenarios to examine the robustness of our findings to uncertainties about key parameters.

Table S2(a). Sensitivity analysis

			Benchmark	33% productivity assumption	High price elasticities of yields	Zero price elasticity of yields	Low yield trends	High yield trends	High soil rental payment
			Benchmark	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)	Scenario (5)	Scenario (6)
			(1)	(2)	(3)	(4)	(5)	(6)	(7)
Total cropland In 2012 (M ha)	Scenario 1	(a)	130.4	129.2	129.9	130.4	130.5	130.4	130.1
	Scenario 2	(b)	131.6	131.1	131.3	131.7	131.7	131.5	131.4
		(c=(b-a)/a)	1.0%	1.4%	1.1%	1.0%	0.9%	0.9%	1.0%
		d*		0.4%	0.1%	0.0%	0.0%	-0.1%	0.0%
Reduction in marginal land (M ha)	Scenario 1	(a)	16.6	13.9	15.5	16.7	16.9	16.7	16.1
	Scenario 2	(b)	19.8	18.4	19.0	20.0	20.0	19.5	19.2
		(c=(b-a)/a)	18.9%	32.8%	22.6%	19.7%	17.9%	17.2%	19.5%
		d*		13.8%	-3.7%	0.8%	-1.0%	-1.8%	0.6%
Corn price in 2012 ($ per MT)	Scenario 1	(a)	134.7	134.8	121.7	134.7	141.1	131.5	134.7
	Scenario 2	(b)	160.1	160.6	144.9	166.8	166.8	154.4	160.6
		(c=(b-a)/a)	18.9%	19.2%	19.1%	23.8%	18.2%	17.4%	19.3%
		d*		0.3%	0.2%	5.0%	-0.7%	-1.4%	0.4%
Total CRP maintenance costs (Billion $)	Scenario 1	(a)	13.0	9.4	12.7	13.0	13.2	12.9	13.2
	Scenario 2	(b)	13.5	9.6	13.5	13.5	13.5	13.4	13.6
		(c=(b-a)/a)	3.5%	2.4%	6.0%	3.9%	2.2%	3.9%	3.1%
		d*		-1.1%	2.4%	0.3%	-1.3%	0.3%	-0.5%

Notes: 1. Scenario 1 is an "Ethanol fixed at the 2007 level" scenario and maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period. Scenario 2 is an "Ethanol at the observed levels with RFS" scenario and imposes observed corn ethanol production (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

2. d*: numbers reported in these rows are the differences in 'c' between columns (2)-(7) and column (1).

Table S2(b). Sensitivity analysis

			Benchmark	High yields on cropland -pasture	High conversion costs of CRP	Discount rate of 3%	High rates of export growth	Increased availability of cropland-pasture	A combined scenario
			Benchmark	Scenario (7)	Scenario (8)	Scenario (9)	Scenario (10)	Scenario (11)	Scenario (12)
			(1)	(2)	(3)	(4)	(5)	(6)	(7)
Total cropland	Scenario 1	(a)	130.4	130.5	130.1	130.4	130.6	130.5	130.7
In 2012 (M ha)	Scenario 2	(b)	131.6	131.7	131.4	131.6	131.7	131.9	131.9
		(c=(b-a)/a)	1.0%	0.9%	1.0%	1.0%	0.9%	1.0%	0.9%
		d*		-0.1%	0.0%	0.0%	-0.1%	0.0%	-0.1%
Reduction in	Scenario 1	(a)	16.6	17.1	16.0	16.7	17.1	17.1	17.6
marginal land	Scenario 2	(b)	19.8	19.9	19.3	19.8	20.0	20.4	20.4
(M ha)		(c=(b-a)/a)	18.9%	16.6%	20.4%	18.9%	17.0%	19.1%	16.2%
		d*		-2.3%	1.4%	-0.1%	-1.9%	0.1%	-2.8%
Corn price in 2012	Scenario 1	(a)	134.7	134.7	134.7	134.7	138.0	134.7	137.9
($ per MT)	Scenario 2	(b)	160.1	158.9	160.6	160.1	163.6	159.2	172.9
		(c=(b-a)/a)	18.9%	17.9%	19.3%	18.9%	18.6%	18.2%	25.3%
		d*		-0.9%	0.4%	0.0%	-0.3%	-0.7%	6.5%
Total CRP	Scenario 1	(a)	13.0	12.5	12.2	13.4	13.2	13.0	12.1
Maintenance	Scenario 2	(b)	13.5	12.9	12.7	13.8	13.5	13.5	12.4
costs (Billion $)		(c=(b-a)/a)	3.5%	3.0%	4.5%	3.4%	2.4%	3.6%	2.9%
Total CRP		d*		-0.5%	1.0%	-0.2%	-1.1%	0.1%	-0.7%

Notes: 1. Scenario 1 is an "Ethanol fixed at the 2007 level" scenario and maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period. Scenario 2 is an "Ethanol at the observed levels with RFS" scenario and imposes observed corn ethanol production (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

2. d*: numbers reported in these rows are the differences in 'c' between columns (2)-(7) and column (1). A combined scenario assumes zero price elasticity of yields, high yields on cropland-pasture, high rates of export growth and high conversion costs of CRP.