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

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The authors are grateful for funding from the National Science Foundation and NIFA/USDA for this research. Seniority of authorship is shared equally.

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Abstract:

The increase in corn ethanol production has raised concerns about its indirect impacts on the expansion of cropland and implications for the environment and continues to be a controversial issue. In particular, land enrolled in the Conservation Reserve Program (CRP) declined by 7.2 million acres between 2007 and 2012 while corn ethanol production more than doubled. 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 unused cropland, including 1 million acres in CRP, to crop production. While substantial in magnitude, we find that these land use changes due to biofuel production accounted for only 16% and 13% of the total reduction in unused cropland and in CRP acres, respectively, that occurred over the 2007-2012 period. We also find that the land use change per million gallons of corn ethanol has declined non-linearly over time from 453 acres to 112 acres over the 2007-2012 period.

Key words: Corn ethanol; food prices; Conservation Reserve Program; unused cropland

I. Introduction

There has been considerable interest in promoting biofuels as a low carbon, renewable alternative to fossil fuels across the world [1]. However, the production of biofuels from food crops has an unintended consequence of diverting land from food and feed production to fuel production, raising prices of food and feed and converting non-cropland to crop production across the world [2,3]. Assessment of the extent of this land use change due to food crop based biofuels is critical to understanding the trade-offs between food and biofuel production. Several studies have examined the effects of using food crops and non-food, energy crops on land use change and the accompanying effect on food prices [2–6]. These studies show that expanded global biofuel production is expected to reduce land allocated to food crops and raise food prices [2,3] and point out that biofuels produced from dedicated energy crops can mitigate the adverse effects of biofuel production on food prices and provide desirable environmental benefits [4–6]. This paper focuses in particular on examining the extent to which there was conversion of environmentally sensitive land enrolled in the Conservation Reserve Program (CRP) to crop production in the US due to higher crop prices induced by the growth 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 land that was not being used for crop production or had been retired from crop production. This includes land enrolled in the Conservation Reserve Program (CRP) that was retired from crop production for environmental reasons since 1985. 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 land enrolling in CRP between 2007 and 2012. This has raised concern because expansion of cropland on land in CRP or land previously unused for 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 [7–9]. It could also exacerbate other environmental problems such as nitrate run-off and soil erosion that degrade water quality [10].

Satellite data show a decline in land enrolled in the CRP and other types of grasslands and a corresponding increase in cropland in the US since 2007 [11,12]. Wright et al.[13] estimate that 4.2 million acres of 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. These data implicitly implicate corn ethanol as the primary cause of this conversion of cropland 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 [14–16]. Barr et al.[15] 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 production since 2007. Isolating this impact is complicated because it involves comparison of observed changes in total US cropland and decline in CRP acres with biofuels to an unobserved counter-factual without the increase in biofuels while holding all other factors constant. It also requires estimating the land

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

use impacts simultaneously with the effects on crop prices since the latter influences the returns to cropland and the incentives to expand 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 [17]. For instance, Searchinger et al. [8] use the Food and Agricultural Policy Research Institute (FAPRI) model to examine the direct and indirect land use changes due to corn ethanol production. Beach and McCarl [18] 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. Hertel et al. [19] and Taheripour et al.[20] use the Global Trade Analysis Project (GTAP) model to examine the indirect land use changes on various land use categories due to corn ethanol production. These studies have either assumed that land enrolled in CRP is fixed at 2007 levels [18] or have not specifically examined the implications for acres enrolled in the CRP [20]. 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. In examining the impact of corn ethanol production on CRP acres it is also important to consider other types of land that could have been converted to crop production. We therefore also examine the incentives for converting other unused cropland (not enrolled in CRP) to active crop production. We define unused cropland as land that is intermittently used for crop production and is referred to as land enrolled in CRP and cropland pasture defined by USDA's National Agricultural Statistics Service (NASS). Cropland pasture is either in a crop-fallow rotation or used for pasture and grazing[2]. We distinguish this from cropland which is defined here to include acres in active crop production only.

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 unused cropland to crop production in the US over the 2007-2012 period [21–23]. We use a dynamic definition of unused cropland 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 categorized as cropland pasture by NASS 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 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 unused cropland 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 expansion of cropland and on crop prices, we simulate two scenarios with the

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[2] For definitions of different land uses, see page 17 of the following document https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usappxb.pdf

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 outcomes 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 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 unused cropland to crop production adds to stock of cropland capacity that can be used year after year to support increased ethanol production. This is distinct from the static view of land use change that attributes all of the change in unused cropland to a one-time shock in the level of ethanol production. Lastly, this paper extends the version of BEPAM developed in Chen et al. [23] 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. [23], Hudiburg et al. [22] and Huang et al. [24]. 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. We show that the estimates 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 [existing models are reviewed in ,17,25]. Unlike estimates from the FAPRI and GTAP models [8,20,26] 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.

We find that the expanded corn ethanol production between 2007 and 2012 led to a conversion of 3.2 million acres of land previously in CRP and cropland pasture to crop production, accounting for about 13% of the total reduction in unused cropland over the 2007-

2012 period. We also find a low responsiveness of aggregate crop acreage in the US to price increases induced by biofuels with an elasticity of land use change to land rents of 0.066. These findings imply that while corn ethanol led to some conversion of unused cropland to crop production, it only explains a relatively small share of the land use changes in the US in recent years. Although the focus of this paper is on examining the effects of corn ethanol on land use changes in the US, the framework we developed here can be easily applied to other countries to isolate land use changes due to biofuels.

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 [23]. 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

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[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.

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 [23].

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, cropland pasture is considered to be unused cropland because it is intermittently in crop production. CRP acres are also considered unused cropland since they 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 in each CRD can be converted to crop production if the net returns from the conversion to crop production are larger than the costs of conversion in that CRD. We assume that cropland pasture acres are relatively low quality cropland and that the potential returns from using it for crop production are equal to those from the least profitable crop in the CRD. We also assume that the reason the land is not used for crop production is because the cost of converting cropland pasture to crop production is at least as high as 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. 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 expected to increase. This creates an incentive for conversion of expiring CRP acres and 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

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[4] Our analysis is based on a simplifying assumption that all unused cropland 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 unused cropland 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.

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 [27–29]. 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 CRP acres and 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. [23].

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. [23].

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 in 2007, 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 unused cropland

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.[23]. 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 (we discuss this below) Thus, we selected this productivity assumption as our benchmark productivity assumption. We also follow Hertel et al. [19] 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 (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 unused cropland 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 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 Expansion of Cropland 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[5]. 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 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 unused cropland (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

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[5] The US agricultural census data indicate that cropland pasture acres declined significantly from 37.6 million acres in 2007 to 12.9 million acres in 2012. However, this may have at least in part occurred due to a change in the definition of cropland pasture. Our analysis is not explaining all changes in cropland pasture acres; it is only explaining the changes due to expansion in corn ethanol production.

million acres of cropland pasture. This represented 16% and 13% of the reduction in unused cropland and in CRP acres, respectively, in Scenario 2 over the 2007-2012 period. On an annual basis, the conversion of unused cropland (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 (last column of Table 1).

We examine the implications of our estimates of the land use change that can be attributed to corn ethanol by converting the total changes in marginal land to a per gallon estimate. We estimated 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 (figure 2b). Thus, the indirect land use effect of corn ethanol has declined over time.

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, 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. [8] and USEPA [30].

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.[15] and Swinton et al.[16], 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 Unused Cropland

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 Scenario 1. The conversion of unused cropland 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 unused cropland (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 with those obtained under Scenario 1.

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 (figures 4a and 4b). While cropland acres under wheat declined by 2.3 million acres, 1.4 million acres of unused cropland 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 unused cropland 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 (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, 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 1 (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 unused cropland (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 unused cropland, 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 unused cropland 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 relative to Scenario 1 under the benchmark assumptions and under each of the alternative parameter assumptions.[6] 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.[7] 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 (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.[8] Estimates of the conversion of unused cropland (CRP and cropland pasture)

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[6] These percentage changes are reported in rows ‘c’ of table S2(a) and (b) in the Supporting Information.
[7] Results are reported in rows ‘d’ of table S2 (a) and (b) in the Supporting Information.
[8] 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.

due to corn ethanol over the 2007-2012 period were within ± 5% of the estimate obtained in the benchmark case.[9] 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 expansion of cropland due to conversion of unused cropland 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 unused cropland accounted for about 13% of the total reduction in unused cropland over the 2007-2012 period. While corn ethanol was responsible for a substantive increase in cropland as noted by

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[9] 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 amount of unused cropland converted to crop production under both scenarios was 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 unused cropland in this scenario was smaller, that led to a larger estimated impact of corn ethanol on the conversion of unused cropland as compared to the benchmark estimate. In absolute terms, the reduction in unused cropland that can be attributed to corn ethanol ranged between 2.8 and 4.6 million acres across the various parametric assumptions considered here.

Wright et al. [13], it is important to note that cropland expanded by only 1% between 2007-2012 relative to the level of cropland acres with the 2007 level of corn ethanol. Our findings of the low overall 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. [15], Swinton et al. [16] and Leal et al. [31]. 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 and other crops was converted to corn.

Of the total expansion in crop production and cropland acres, 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 previously unused cropland. 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 cropland acres 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 [25,32]. 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 unused cropland, 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 declined 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 [8,19,30,33]. Regulatory agencies, such as the US Environmental Protection Agency 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. 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 unused cropland 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 unused cropland due to corn ethanol in year t (e=c+d-a-b)	% change in unused cropland 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 unused cropland (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 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.

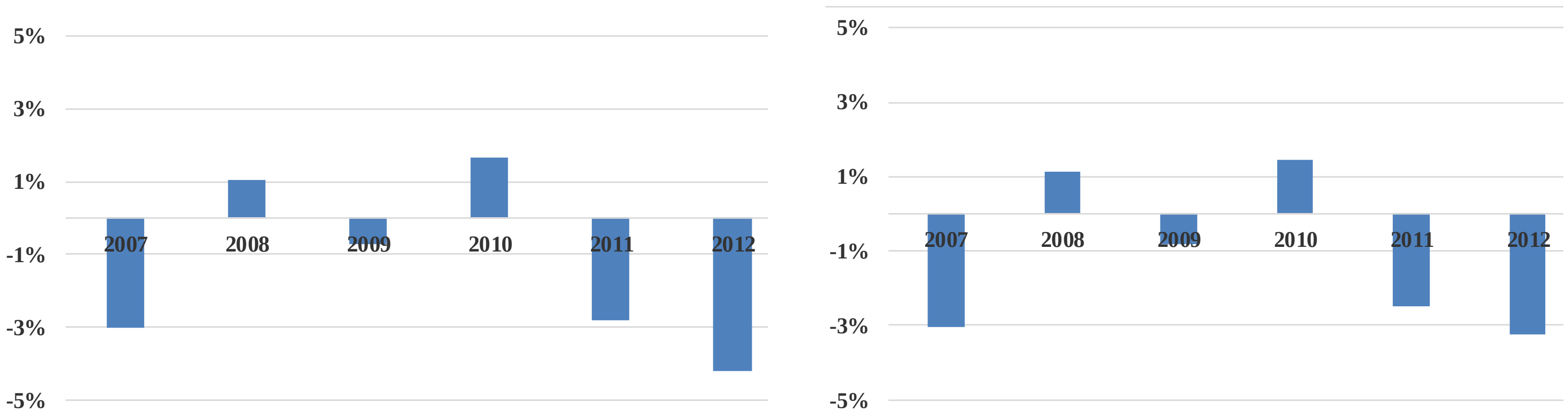
[3] Numbers in this row denote the sum of the total reduction in CRP acres by 2012 and the amount of cropland pasture converted in 2012 under Scenarios 1 and 2, respectively.

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%)

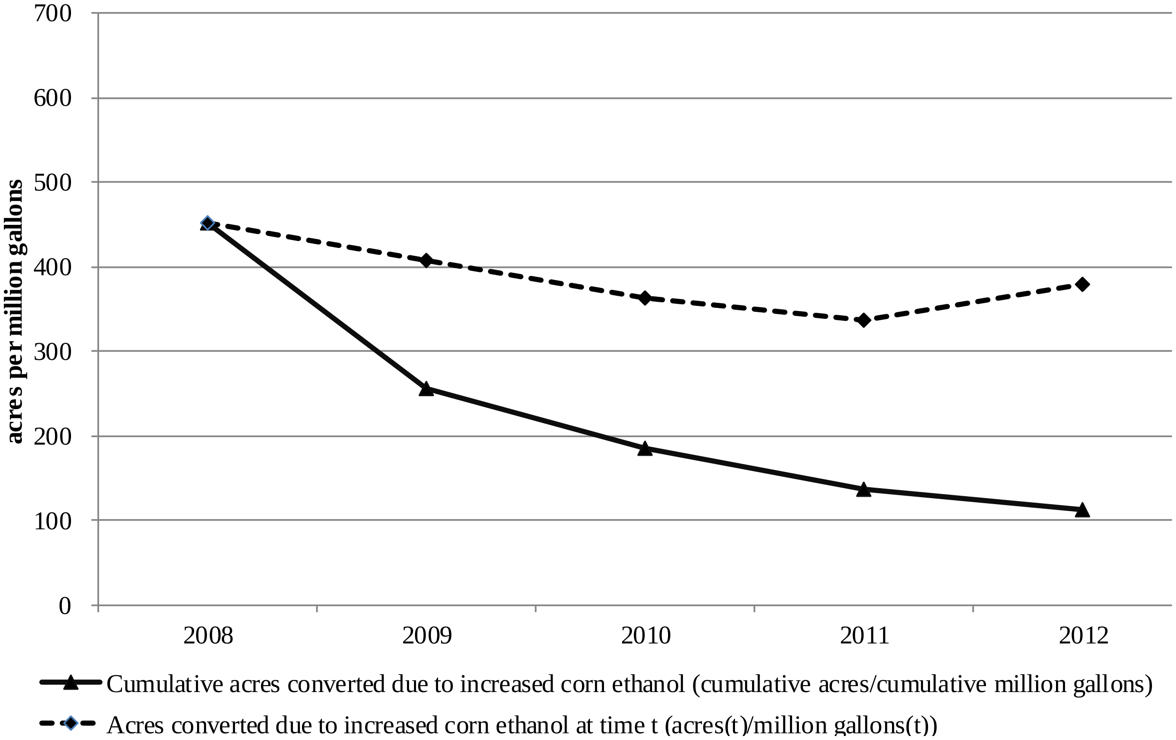
Notes: [1] Scenario 1 maintains corn ethanol production at the 2007 level (6.5 billion gallons) for the duration of the 2007-2012 period, while Scenario 2 imposes observed corn ethanol production with the RFS (that increased from 6.5 billion to 13.2 billion gallons) over the 2007-2012 period as the constraint.

[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.

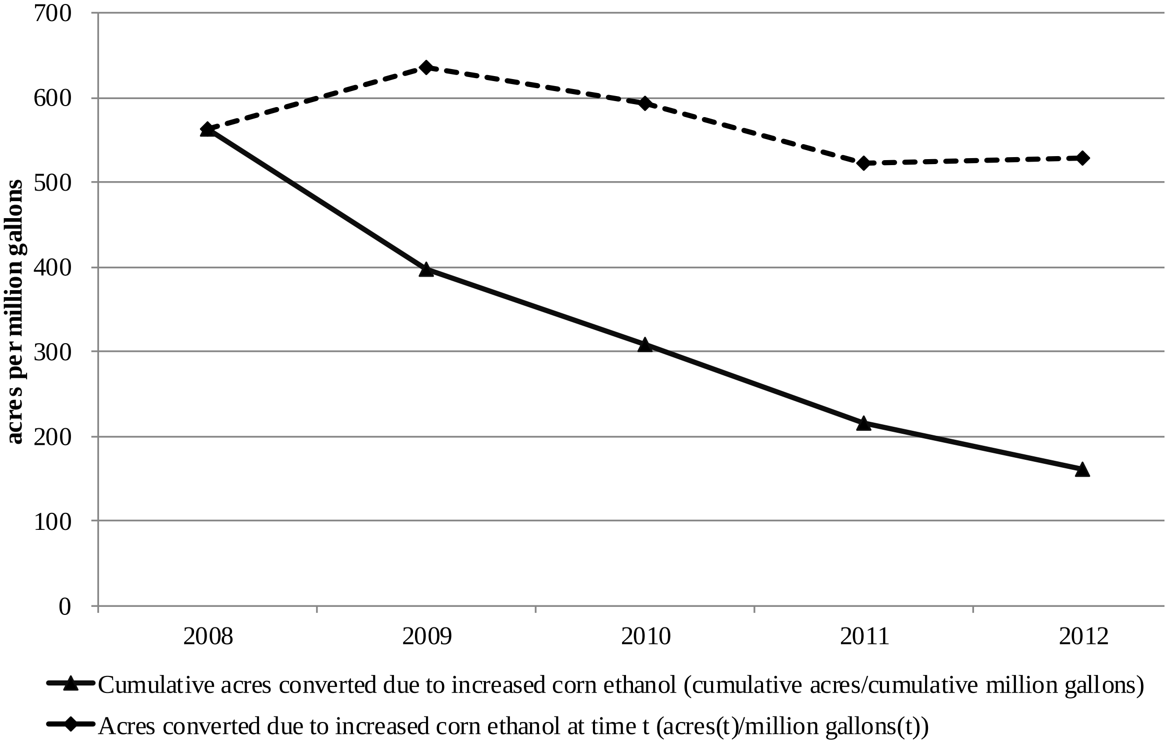


(a) Benchmark productivity assumption (b) 33% productivity assumption

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



(a) Benchmark productivity assumption



(b) Assumed 33% productivity assumption

Figure 2. Unused cropland converted due to increased corn ethanol production

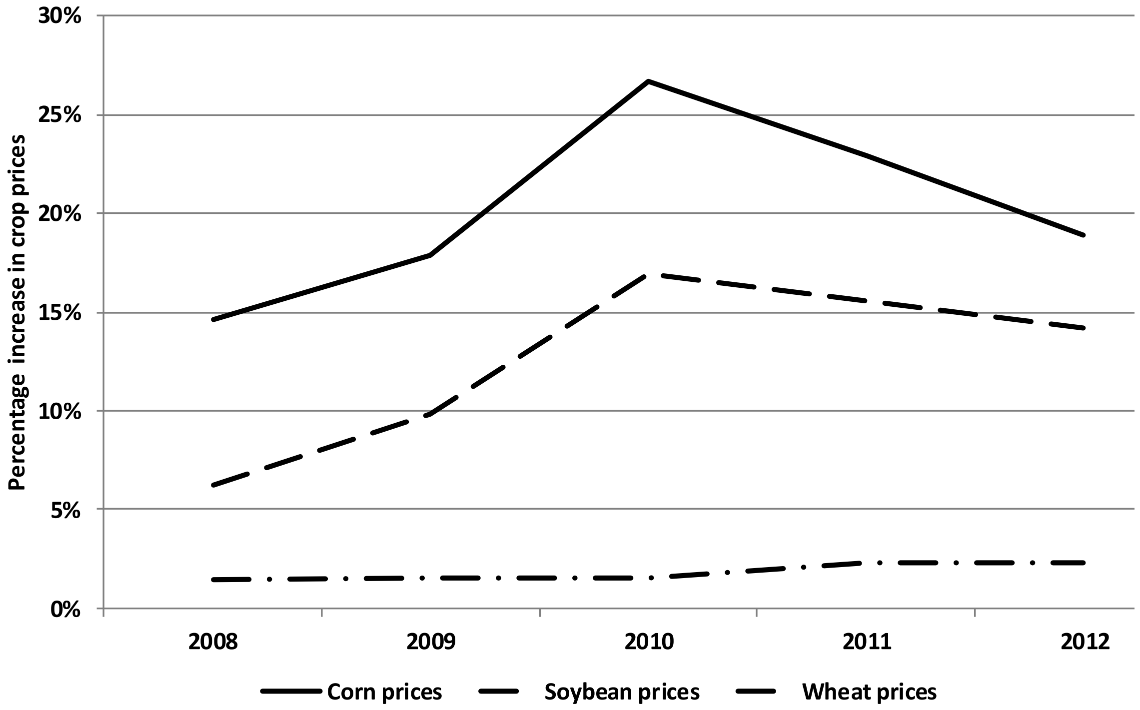
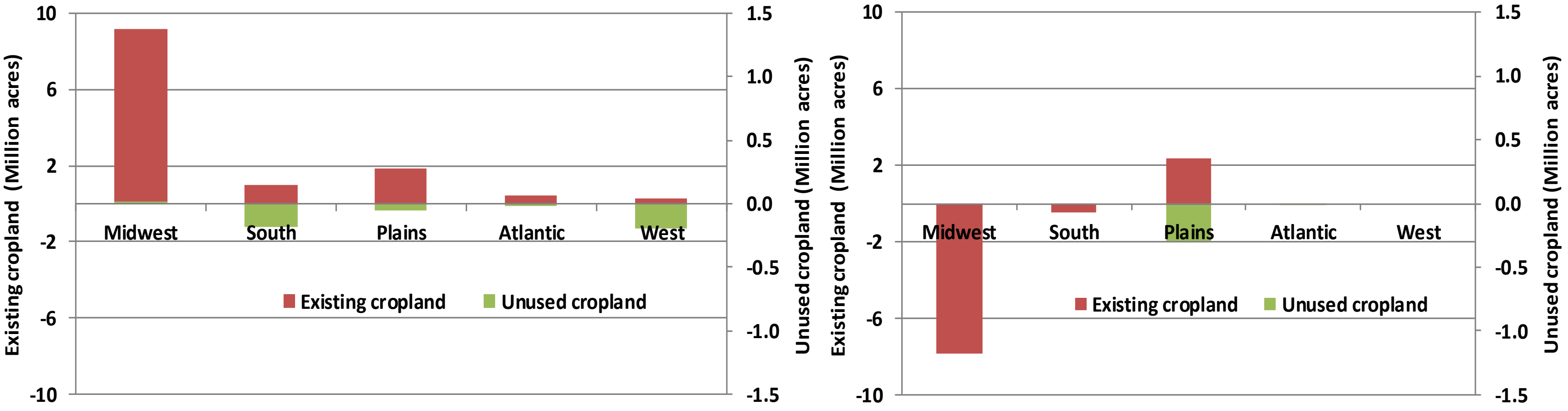
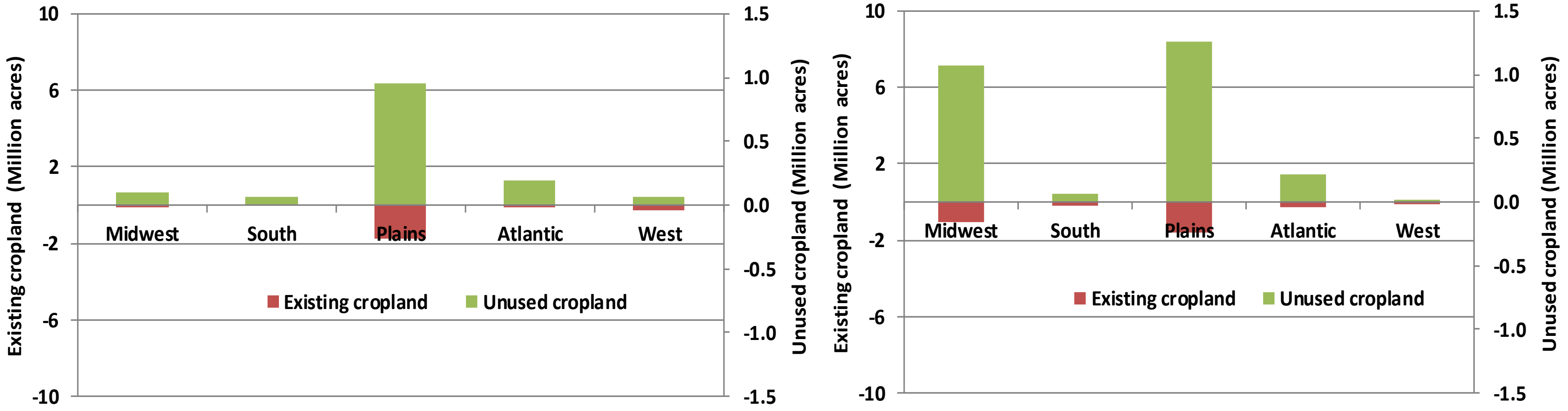


Figure 3. Impact of corn ethanol production on crop prices

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.



(a) Corn (b) Soybeans



(c) Wheat (d) Alfalfa

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 unused cropland. 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.

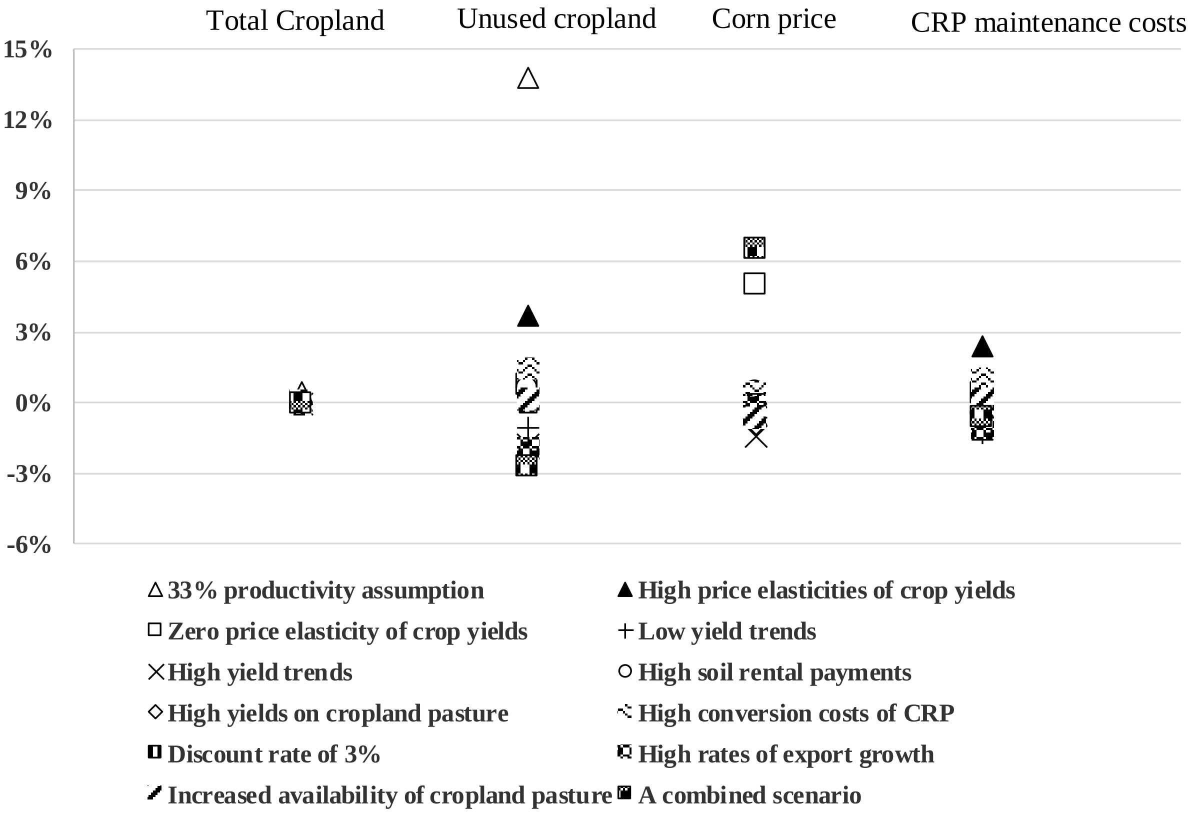


Figure 5. Sensitivity analysis: Deviation in the Percentage Change due to Biofuels Under the Benchmark Parameters and Under each Alternative Parametric Assumption

Notes: A value close to zero indicates that model outcomes under the benchmark assumptions were close to those under the alternative parametric assumption.