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Submitted Article

# Ethanol Plant Location and Land Use: A Case Study of CRP and the Ethanol Mandate

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**Abstract** *This study uses a county-level difference-in-difference framework to estimate the share of re-enrollment into the Conservation Reserve Program (CRP) in response to local ethanol production capacity after the Renewable Fuels Standard (RFS). Relatively more land remained in CRP in ethanol-intensive areas after the RFS. This seemingly counter-intuitive result can be explained by post-RFS changes to the CRP that favored ethanol-intensive areas. Both CRP design changes and production trends correlated with ethanol plant location pose challenges for empirical strategies that use ethanol plant location to study production or land use decisions. Changes to CRP policies can play an important role in participation and land use decisions.*

**Key words**: Conservation Reserve Program, Renewable Fuel Standard, Ethanol.

**JEL codes**: Q15, Q18, Q28.

Ethanol production in the United States has seen about a four-fold increase under the Federal Renewal Fuel Standard (RFS), which was first enacted in 2005 and subsequently revised in 2007. The 2007 revision mandates an annual consumption of 15 billion gallons of ethanol by 2015, eventually increasing to 36 billion gallons by 2022 (U.S. Environmental Protection Agency 2016). The period beginning 2008 through the present has also seen an enrollment decline in the U.S. Federal Conservation Reserve Program (CRP) by about 10 million acres (USDA Economic Research Service 2015) from a peak of nearly 37 million acres in 2007 (Stubbs 2014). The CRP is a voluntary federal program that offers farmers the option of retiring environmentally sensitive tracts of farmland that are currently in production in lieu of an annual rental payment. The contract period for enrollment is generally 10 years. During periods of high crop prices, land expiring from the CRP would be subject to reversion to crop production. Hendricks and Er (2018) suggest that CRP land was a prominent factor in land use change during the recent period of high commodity prices.

This study examines the relationship between ethanol plant location and CRP re-enrollment after the ethanol mandate. Understanding the effect of ethanol mandates on CRP enrollment is important for a few reasons. First, CRP provides important environmental services, which might be lost as land returns to commercial crop production (Secchi and Babcock 2015). Second, land under CRP contracts, together with pasture land, may serve as the extensive margin for crop production. Expectations about commodity prices affect land owners' incentives to enroll, re-enroll or dis-enroll land under the program. Third, the greenhouse gas (GHG) emissions associated with (re)converting CRP to cropland might reduce the GHG benefits of crop-based biofuels. Several studies have speculated that the emissions associated with land cover change could render biofuel policies counterproductive to climate change mitigation (Fargione et al. 2008; Searchinger et al. 2008; Melillo et al. 2009; Hertel et al. 2010; Lapola et al. 2010).

The magnitude of land cover change and associated emissions in such studies is wide-ranging. Predictions on the higher end are that about 500 acres of non-cropland would be converted to cropland per each million-gallon increase in U.S. corn ethanol production (Searchinger et al. 2008; USEPA 2010). On the other hand, Chen and Khanna (2018) estimate that land use change as low as 112 acres being converted per million-gallon increase in corn ethanol production during 2007-12. Being simulation-based, the estimates of land cover change from all such studies mentioned above are hypotheses that require empirical validation. Since crop prices that drive agricultural land use are the product of multiple interacting demand and supply shocks, only one of which is shifting biofuel demand, identifying the causal effect of growth in biofuel production on land use change (LUC) is challenging. Rising affluence, energy prices, adverse weather, and barriers to trade are at least four other shocks to have contributed to high crop prices during the last decade (Gilbert 2010).

High-resolution satellite images of agricultural land cover change for the western corn belt (Iowa, Minnesota, North Dakota, South Dakota, and Nebraska) show a decline in total grassland area of more than half a million acres between 2006 and 2011 (Wright and Wimberly 2013). This study, however, only establishes the overall correlation between high crop prices and LUC, and not a causal effect of ethanol mandates on LUC. For instance, the correlation between increase in the profitability of crop production and the increase in crop-planted area in the prairie states suggests that cropland supply is inelastic (Barr et al. 2011). Specifically, Swinton et al. (2011) find that between 2006 and 2009, when profitability of the typical farm increased 64%, crop-planted area increased only 2%. Overall, causal estimates of the effect of biofuel policies on the encroachment of cropland into land set aside for nature are lacking, which provided the motivation for this study.

There is a large body of literature on factors influencing CRP enrollment decisions, optimal program design, rental rates, and several other issues. A literature review by Wachenheim et al. (2014) emphasizes that the economics literature on CRP collectively indicates that landowners respond to financial incentives, but are also influenced by both uncertainty related to program design and non-financial influences, such as preferences for the environmental benefits provided by CRP. There is also a rich body of literature on the auctions used for CRP enrollment and the potential for improvements (e.g., Hellerstein et al. 2015). Economists have also considered the implications of the post-2007 decline in total land enrolled in CRP (Wu and Weber, 2012). Jointly, several studies support the economic and environmental benefits of the CRP as well as the importance of considering factors beyond commodity prices.

Program changes occurring around the time of the mandate favored land with smaller parcels or more environmental benefits. Typically a landowner can sign up for CRP under one of two programs—general signup and Continuous CRP (CCRP). While land enrolled in the 1990s would have been through a general sign-up, in the 2000s different CRP programs, collectively referred to as CCRP, allowed for smaller parcels with more demonstrated environmental benefits to automatically enter CRP (Stubbs 2014). General sign-ups take place during fixed periods and involve competitive bidding by landowners. The USDA's Farm Service Agency (FSA), which administers CRP, accepts bids after ranking them on environmental benefits and cost. In contrast, smaller parcels may be enrolled under the CCRP at any time without bidding or ranking, so long as the landowners undertake specified land management practices and the land meets certain eligibility criteria based on its environmental characteristics. CCRP was becoming more prominent during the mid 2000s and may have facilitated re-enrollment. Temporary extension or re-enrollment (REX) contracts were also broadly offered in the late 2000s for expiring contracts on more environmentally sensitive land, or land with a higher Environmental Benefits Index (EBI; Farm Service Agency). Decreases in the acreage cap post-mandate may also have played a role in the national decline in CRP acreage (Hendricks and Er 2018).

Several studies have used ethanol plant location to estimate the impact of ethanol production and related policies on a variety of outcomes related to crop production, including farmland value and land rents (Henderson and Gloy 2009; Blomendahl et al. 2011; Towe and Tra 2013; Kropp and Peckham 2015), local grain price (McNew and Griffith 2005), farm size (Tra and Towe 2016), various measures of land use such as area planted to corn, total agricultural area, intensification, and effect of corn-soy rotation (Miao 2013; Arora et al. 2016; Motamed et al. 2016), and landowners' decision to exit early from CRP and return to farming (Krumel Jr. et al. 2015). By decreasing the local basis, or transportation costs to deliver crops to market, ethanol plants make local crop production more profitable. Beyond changes to the local basis, ethanol plants may even improve local expectations for future farm income (Towe and Tra 2013).

There is a growing body of research that shows that ethanol production is associated with local intensification of corn production as well as more land coming into production (Brown et al. 2014; Motamed et al. 2016). Using a county-fixed effects model, we extend this literature to consider the impact of ethanol plant capacity on local CRP enrollment decisions. We find that a larger share of land re-enrolled in CRP in counties with growing ethanol capacity after the biofuel mandate went into effect. This result, however, should not be interpreted as implying that the mandate itself led to less land leaving the CRP, as it only holds for counties with land more likely to be affected by post-mandate CRP changes. Overall, our results suggest that land that exited CRP was not necessarily driven by proximity of an ethanol plant, but that CRP design changes effectively served to keep relatively more land enrolled near ethanol plants.

## Data

Our study focuses on ten Midwestern states—Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin—which together consistently account for the vast majority of U.S. ethanol production. Our data spans the years 1999 through 2014. Since these states are also among the largest corn-growing states, this indicates that proximity to sources of feedstock is a major factor in ethanol plant siting decisions.

We combine several sources of county-level data for our analysis. The location, company name, feedstock, and total plant capacity are reported by the Renewable Fuels Association. There are 199 ethanol plants accounted for in our data set, with 40 in operation in 1999, 71 in 2005, 100 in 2007, and 182 by 2014. Ethanol capacity is measured by millions of gallons per year (mgpy). The latitude and longitude of each plant location is calculated as the centroid of the city in which it operates, as reported by Google Maps. Each city is then matched with the county in which it is located. The distance between each county's centroid and the nearest ethanol plant (in operation) is determined using the GEODIST package in Stata. We use capacity of ethanol plants within an 18.5-mile and 31-mile radius of each county centroid (the 0.25 an 0.50 percentiles for distance to the nearest ethanol plant, respectively), and estimate our empirical model under each specification. This allows us flexibility in considering differences in local transportation infrastructure, which would affect transportation costs and production decisions. While we only report results using the 18.5-mile radius, results with the 31-mile radius are consistent and available upon request.

We use county-level data on CRP enrollment, broken down into details of acres expiring, acres re-enrolling, and new acres entering the program, as well as the total stock of acres enrolled and CRP rental payments. CRP rental payments form the base of payments to landowners, and allow for payments to adjust upwards based on market conditions and compete with local cropland rental rates. This data is collected by the USDA Farm Service Agency (FSA) and county-level aggregates are estimated by the USDA Economic Research Service (ERS). CRP contracts are typically ten years, although the length of the contracts varies with contract type and has changed across Farm Acts. We are specifically interested in re-enrollment of land that expires, as enrollment decisions are from over a decade ago. Most land expiring during our study period would have been from land enrolled under a general or competitive sign-up.

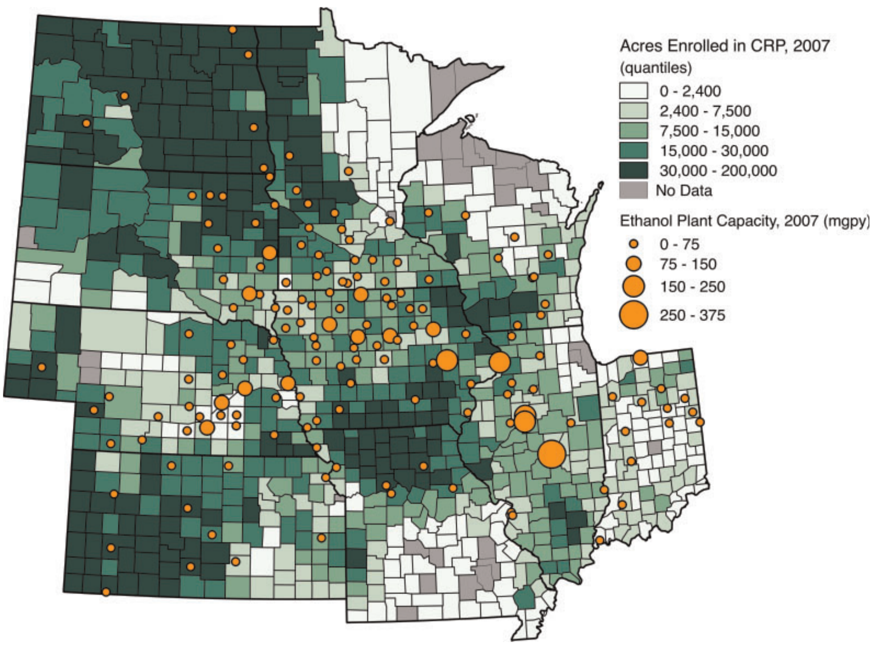
We obtained data on average county-level CRP parcel size and soil quality to allow us to consider the impact of program changes on re-enrollment decisions. We also use NASS data on state corn prices and county-level cash rents. To compare our analysis with that of related studies, we also include measures of the intensive and extensive margins of corn production: (*a*) acres of corn planted as a share of total acres of corn and soy planted, and (*b*) total corn acres planted. This county-level data on corn and soybean production is reported annually.

Summary statistics for all variables are provided in table 1. A map of ethanol plants and CRP acreage in 2007 is reported in figure 1. As discussed previously, there was a great deal of variation in both CRP enrollment and

**Table 1** Summary Statistics, County-level Averages

| | Ethanol Cap. >0 | | Ethanol Cap. =0 | |
|---|---|---|---|---|
| **Variables** | **Mean** | **St. Dev.** | **Mean** | **St. Dev.** |
| Ethanol Capacity (mgpy, w/in 18.5 miles) | 72.2 | 70.1 | 0.00 | 0.00 |
| CRP Acres (total) | 17,008 | 17,864 | 22,258 | 25,009 |
| CRP Acres (first time enrollment) | 601 | 481 | 783 | 1,232 |
| Average Farm Size (acres in operation) | 411 | 180 | 466 | 359 |
| Median Farm Size (acres in operation) | 180 | 89 | 195 | 178 |
| CRP Rent Per Acre (USD) | 97.4 | 32.2 | 76.4 | 31.0 |
| Share of CRP Acres Re-Enrolled | 0.28 | 0.34 | 0.39 | 0.56 |
| Corn Intensity | 0.62 | 0.10 | 0.57 | 0.16 |

**Figure 1** Ethanol plants and CRP acres, 2007




ethanol plant numbers and capacity over our study period. Data for counties with and without an ethanol plant reported in table 1 indicate substantial differences, which informs our empirical strategy.

## Empirical Strategy

We investigate the effect of the federal biofuel mandate on land use change by estimating the effect of changes to local ethanol capacity on CRP re-enrollment decisions. We argue that while federal biofuel policies might have contributed to higher global commodity prices, the presence of an ethanol plant, as a local demand shifter, introduced spatial variation in crop prices and land value. This variation can be attributed to the local ethanol plant, while price shocks reflect broader economic conditions and other demand shifters. Ethanol plants introduce this variation by reducing the cost of transporting the crop to market (often referred to as the basis), as opposed to broader changes in price, which are driven by many factors and benefit all producers. The presence of an ethanol plant may also have an impact beyond improvement in the local basis, which Towe and Tra (2013) identify and refer to as "vegetable spirits"—the effect that cannot be explained by these economic fundamentals. Regardless of the mechanism, the location of an ethanol plant has been shown to be related to local production decisions (i.e., (Miao 2013; Fatal and Thurman 2014; Motamed et al. 2016)) and is hence a potentially useful tool to isolate the impact of the ethanol mandate. This includes several periods, 1997–2009 (Miao 2013), 2006–2010 (Motamed et al. 2016), and 2002–2008 (Fatal and Thurman 2014), where ethanol plant location has been shown to be related to larger corn production.

One plausible hypothesis is that counties with higher ethanol production capacity are likely to see a relatively smaller share of land re-enroll in CRP. However, ethanol plant location is unlikely to be randomly assigned. Instead, ethanol plants are likely located in counties that provide easy and low cost access to feedstock, that is, corn in the case of the Midwestern United States (Low and Isserman 2009; Motamed et al. 2016). To minimize the cost of transporting feedstock from the farm gate to the ethanol plant, plants might locate in counties with higher-quality cropland or superior access to transportation networks. If such counties have CRP land that is higher quality than average, then such counties may experience a greater decline in the share of farmland under CRP than counties with lower-quality CRP land. However, given that the post-mandate crop price shock fundamentally altered production incentives, the impact of the RFS on CRP enrollment is an empirical question.

In the literature, the endogeneity of plant-siting decisions is typically controlled for by using a combination of fixed effects, matching estimators, and instrumental variables. Towe and Tra (2013) use an increase in ethanol plant capacity within a given vicinity of a parcel of farmland to identify the capitalization effect of the RFS's 2005 mandate. These authors use a difference-in-difference propensity score matching estimator to control for the non-random selection of ethanol production facilities; they find that the addition of new ethanol capacity had a significant positive effect on farmland value post-RFS, but not so prior to the RFS. However, these authors use parcel-level data, while we only have access to county-level data. Krumel Jr. et al. (2015) estimate the impact of ethanol plant location on farmers' decision to exit the CRP before contract expiration from 2007 to 2013. While most land only leaves the program upon expiration, a small share of contracts left the program early and repaid all past CRP payments during this period of high commodity prices. Krumel Jr. et al. (2015) find a significant positive effect of ethanol plants driving early exit from the CRP, suggesting an important role of ethanol plants on land use decisions. However, these authors do not consider exits before and after the ethanol mandate.

Similar to (Krumel Jr. et al. 2015) and others, we attempt to control for the plausible non-randomness of ethanol plant location through county fixed effects. County fixed effects control for time-invariant factors that would have been major drivers of location decisions throughout the study period that may also affect CRP enrollment decisions, including soil productivity and transportation networks. Fixed effects would also control for the average levels of environmentally sensitive land. We further use year fixed effects to control for common factors affecting all counties over time, including commodity price trends. After estimating our main specification, we conduct robustness tests to see if local price shifts that violate this implicit "one price" assumption could be biasing our results.

Given that CRP acreage varies widely by county as well as by county size, we use a scale-independent measure of CRP enrollment. Our dependent variable (CRP) is measured as the share of expiring CRP acres from the previous year that re-enrolled in the CRP program. Use of expiring acres also improves our identification, as land that went into CRP ten or more years ago would arguably be based on decisions unrelated to current market conditions, ethanol plant location, etc. Further, using a relative measure mitigates any concerns about annual variation in number of acres expiring.

Our basic reduced-form estimating equations are (one each for the 2007 and 2005 versions of the RFS), for county $i$ in year $t$:

$$CRP_{it} = \delta_1 EC_{it} + \delta_2 EC_{it} D_{2007} + \beta X_{it} + f_i + \tau_t + \epsilon_{it} \tag{1}$$

and

$$CRP_{it} = \delta_1 EC_{it} + \delta_2 EC_{it} D_{2005} + \beta X_{it} + f_i + \tau_t + \epsilon_{it} \tag{2}$$

where $CRP_{it}$ indicates the share of expired acres from year $t$ – 1 that were re-enrolled in year $t$. Ethanol capacity is indicated by $EC_{it}$ and various time-variant controls by $X_{it}$, which includes county population, oil production, and natural gas production. The binary variables $D_{2005}$ and $D_{2007}$ take the value 1 in the years following 2005 and 2007, respectively. The interaction terms $EC_{it}D_{2005}$ and $EC_{it}D_{2007}$ represent ethanol capacity post-RFS. We are interested in $\delta_2$, which represents the impact of ethanol capacity on CRP after the mandate went into effect relative to pre-mandate. County and year fixed effects are denoted by $f_i$ and $\tau_t$, respectively. Unobserved variation is denoted by the error term, $\epsilon_{it}$. For robustness we consider a few other dependent variables under the same specification, specifically new acres entering CRP, total CRP acreage, and CRP rental payments.

Our empirical approach only controls for endogeneity of ethanol plant location under the strong assumption that counties with an ethanol plant are not experiencing differential time trends that are also correlated with CRP participation decisions and ethanol production. Basically, if ethanol-intensive counties were experiencing different rates of change in the dependent variables that are potentially correlated with ethanol plant location, our results may be biased. Many factors that drive these decisions are fixed, such as soil quality and transportation networks, and hence captured by our county fixed effects. Year effects capture the general commodity price environment, but may not capture local basis shifts, which will be explored in our robustness checks.

The presence of unobserved trends that potentially bias results is a common issue when using a difference-in-difference approach, often referred to as the "parallel trends assumption." Many approaches are used to test for parallel trends. The approach we use is to estimate a pre-mandate (before 2005) county-level fixed effects model that allows for a time trend for counties with and without ethanol plants, $E_{it}$ and $NE_{it}$, [1] respectively.

[1] *The dummy variable* $E_{it}$ ($NE_{it}$) *equals one (zero) in years when the county had positive (no) ethanol capacity, and zero (one) otherwise.*

$$CRP_{it} = \beta_1 X_{it} + f_i + \gamma_{1t} E_{it} t + \gamma_{2t} NE_{it} t + \epsilon_{it} \text{ for each } t < 2005 \quad (3)$$

This approach allows us to isolate time trends independent of county average effects, which are absorbed in $f_i$. We estimate this model for our main dependent variable as well as other variables of interest (CRP re-enrollment, new CRP acreage, total CRP acreage, CRP rental payments, corn share, and corn acres). We test for $\gamma_{1t} = \gamma_{2t}$ and also present $\gamma_{1t}$ and $\gamma_{2t}$ graphically for key variables. Analysis of a broad range of variables allows us to consider the general production and land use trends that might be related to CRP decisions. For example, CRP land may be more likely to be converted to crop production in areas with relatively rapid growth in corn production. On the other hand, CRP land or programs may be different in terms of physical characteristics or program administration in ethanol production areas and hence subject to different trends.

In addition to the analysis of pre-trends, we also examine how "post-trends," specifically CRP program changes, may have influenced post-mandate re-enrollment decisions. Our main approach for doing this is to consider how CRP parcel size and average soil quality influences our results. Given that there is not much time variation in average parcel size and that this is likely endogenous to re-enrollment levels, we do not include this variable in our main specification. Instead, we split our sample based on average 2007 CRP parcel size and re-estimate our main specification for each group (below and above median 2007 CRP parcel size). While data on the average environmental benefits score for CRP parcels is not available, we proxy for this with average county-level soil quality, as measured by NCCPI (National Commodity Crop Productivity Index, as estimated by the USDA NRCS). To further consider how parcel size and soil quality affect enrollment decisions, we interact these measures to further split our sample. If program changes were affecting our result, we would expect these results to vary.

The other potential area of concern is that our model may be biased by local price (basis) shifts that are not controlled for by year or time fixed effects. While local basis shifts during our study period are largely attributed to ethanol plants (Hart 2015), we cannot disprove other local basis shifts. While county-level price data is not readily available, there are several ways to test for potential bias. First, we estimate our model "naively" with state-level corn prices, which may capture broader trends at the state-level that differed from national price shocks but may not be fully exogenous. Next, we stratify our sample by the post-RFS "local basis shift," proxied by change in county-level cropland cash rents from 2008–2014; 2008 was the first year these rental rates were readily available. This allows us to estimate our model in counties by the local level of price or profitability changes. Finally, we estimate our main specification from 2006–2009 only. This approach allows us to look at a shorter time period, which may be less likely to capture any local basis shifts, which, outside of ethanol plants, were likely to either occur over a long period or be less likely to occur during a short period.

Consideration of key production decisions can inform the overall validity or comparability of our empirical strategy by testing for results similar to related studies. Hence, we also estimate our model with two measures of key land use decisions for corn production. The results may also shed light on

**Table 2** Ethanol Capacity and CRP Re-enrollment

| Variables | (1) 2005 RFS | (2) 2005 RFS | (3) 2007 RFS | (4) 2007 RFS |
|---|---|---|---|---|
| Ethanol Capacity | 8.47e-05 | | −3.84e-05 | |
| | (0.000537) | | (0.000448) | |
| Post 2005*Ethanol Capacity | 0.00113*** | | | |
| | (0.000258) | | | |
| Ethanol Cap. Squared | | 2.39e-06 | | 2.29e-06* |
| | | (1.43e-06) | | (1.20e-06) |
| Post 2005*Ethanol Cap. Squared | | 3.17e-06*** | | |
| | | (3.93e-07) | | |
| Post 2007*Ethanol Capacity | | | 0.00128*** | |
| | | | (0.000352) | |
| Post 2007*Ethanol Cap. Squared | | | | 3.35e-06*** |
| | | | | (6.33e-07) |
| Constant | 0.638*** | 0.643*** | 0.639*** | 0.644*** |
| | (0.0543) | (0.0556) | (0.0545) | (0.0556) |
| Observations | 7,966 | 7,966 | 7,966 | 7,966 |
| R-squared | 0.072 | 0.072 | 0.073 | 0.072 |
| Number of counties | 840 | 840 | 840 | 840 |

Note: *Heteroskedasticity robust (Huber/White) standard errors appear in parentheses. Additional controls include county population, year fixed effects and oil and gas production. The average marginal effect of ethanol capacity is.000638, with a std. error of.000488 and p-value of 0.191. Asterisks indicate the following: ***= p<0.01, **= p<0.05, and *= p<0.1.*

the environment in which CRP enrollment decisions were made. First, we consider corn acreage as a share of total corn and soybean acres, which provides a measure of intensification trends. We also look at the extensive margin by considering total acres of corn planted.

## Results and Discussion

Results for our main specification, based on ethanol plants that are located within an 18.5 mile radius of the county centroid, are reported in table 2. We consider ethanol capacity and ethanol capacity squared throughout the entire study period. Given the uncertainty associated with how markets responded to RFS legislation passed in both 2005 and 2007, we consider both years as plausible for when the policy became effective. Over the entire period, on average, ethanol capacity generally did not have a statistically significant relationship with CRP re-enrollment, as indicated by the marginal effect reported below table 2. However, under all specifications, relatively more land re-enrolled in counties with higher ethanol production after the RFS went into effect. This result implies that areas with larger ethanol capacity had more land re-enrolling in CRP after the mandate, relative to before. In light of the overall trend of declining CRP participation during the study period, the result may be more appropriately interpreted as relatively less land leaving CRP in ethanol-intensive areas after the RFS went into effect.

The effect is statistically significant and economically meaningful. For a county with an increase in 100 million gallons per year of ethanol capacity (capacity ranged from zero to 477 million gallons per year, with an average of 11 million gallons over the study period), we estimate that the land leaving the CRP after 2007 was approximately 13 percentage points lower relative to a county whose ethanol capacity did not increase post-RFS. The magnitude and level of statistical significance for 2005 is similar. This result contradicts our original hypothesis that relatively more land would leave the CRP program in ethanol-intensive areas.

We also consider the effect of ethanol capacity after the RFS on total CRP enrollment and new land entering CRP, respectively. Our result for the impact of post-RFS ethanol capacity on these measures, reported in online supplementary appendix table A1, is consistent with the impact on re-enrollment. We find that more total land remains in the CRP program in ethanol-intensive areas after the mandate began, and the effect is statistically significant at the 5% level for ethanol capacity. While the effect of total CRP acreage is challenging to interpret given different counties' sizes, programs available, and CRP expiration dates, it does provide some evidence of an absolute effect in addition to the "relative" impact on re-enrollment. That is, it provides some evidence that the relationship between ethanol capacity and CRP participation decisions does not exist only for relative measures. For new land entering CRP, we note that, although not always statistically significant, the coefficient on post-RFS ethanol capacity is negative across all specifications, consistent with our original hypothesis. This may be related to the costs associated with putting land back into production relative to incentives for taking marginal land out of production. Overall, a very small amount of new land came into CRP in the immediate years following 2005 or 2007.

There were several programmatic changes to CRP that were concurrent with the mandate. While CRP enrollment was stable or increasing before the mandate (USDA Economic Research Service 2015), after the mandate crop prices drastically increased, fundamentally altering incentives to keep land out of production. This structural shift in commodity markets might have brought into play local factors correlated with ethanol plant location, which were not as relevant as before the mandate, and hence not captured in our county fixed effects. Next, we consider the role of CRP policies in driving our main results and further test the robustness of our results using several approaches. We also consider indicators of transactions costs.

### *CRP Design Change Impacts*

As discussed, continuous CRP as well as the REX program began or were used more after the mandate came into effect. While local decisions and average EBI for CRP are unobserved, parcel size is a well-known factor for eligibility for CCRP. Further, smaller parcels may be more likely to have a higher EBI. To consider whether program changes are driving our result, we separate our sample by median parcel size. We also use average soil quality as measured by NCCPI. As indicated in table 3, we are able to replicate our result for counties with smaller parcel sizes, but not

**Table 3** Ethanol Capacity and CCRP/REX Suitability

| | **(1)** | **(2)** | **(3)** | **(4)** |
|---|---|---|---|---|
| | **Higher soil quality** | | **Lower soil quality** | |
| **Variables** | **Below median parcel size** | **Above median parcel size** | **Below median parcel size** | **Above median parcel size** |
| Ethanol capacity | −0.0116 | 0.000418 | 0.000750*** | −0.00123 |
| | (0.00947) | (0.00175) | (0.000274) | (0.00110) |
| Post 2007*Ethanol Capacity | 0.00657* | 0.000323 | 0.000662** | 0.00124 |
| | (0.00376) | (0.00171) | (0.000276) | (0.00103) |
| Constant | −0.0317 | 0.783*** | 0.624*** | 0.829*** |
| | (0.611) | (0.0800) | (0.0685) | (0.0743) |
| Observations | 1,011 | 2,468 | 3,114 | 1,373 |
| R-squared | 0.042 | 0.177 | 0.073 | 0.332 |
| Number of counties | 115 | 291 | 304 | 130 |

Note: *Heteroskedasticity robust (Huber/White) standard errors appear in parentheses. Additional controls include county population, year fixed effects and oil and gas production. Asterisks denote the following: ***= p<0.01, **= p<0.05, and *= p<0.1.*

above-median parcel sizes. This result is only weakly statistically significant in counties with higher soil quality but below median parcel size. However, we also find that in counties with lower soil quality and lower CRP parcel size, coefficients for both ethanol capacity and ethanol capacity after 2007 are positively correlated with CRP re-enrollment with higher levels of statistical significance. These joint indicators of CCRP and REX suitability support a result driven by favorability for these programs being correlated with ethanol plant capacity. For areas with above-median parcel size, there is no relationship regardless of soil quality. Jointly, these results suggest that post-mandate changes to CRP were more important than the impact of local ethanol plants in driving the re-enrollment decision.

Another concern with our results could be that they are driven by program differences in ethanol and corn-intensive states such as Iowa and Illinois. The strength of continuous CRP in individual states may have been also relevant, as programs are run by local USDA offices and sometimes states are involved in cost-sharing.[2] However, our findings are not completely driven by Illinois and Iowa. As indicated in table 4, we see a similar pattern in all other states as well: both groups saw statistically significant higher levels of CRP re-enrollment after the mandate in areas of high ethanol capacity. It is unlikely that the result is driven by institutional factors specific to CCRP use in Iowa and Illinois.

[2]*In one study, Iowa was reported as having both the highest number of farms and acreage enrolled in the continuous CRP program nationwide while Illinois had the 2nd and 5th highest levels, respectively (National Sustainable Agriculture Coalition 2015). However, these two states ranked much lower in terms of total CRP acreage in 2014, with Iowa at 6th overall and Illinois at 11th (Farm Service Agency 2016).*

**Table 4** Ethanol Capacity and CRP Re-enrollment by States

| Variables | (1)<br>IL and IA | (2)<br>All other states |
|---|---|---|
| Ethanol Capacity | 0.000543* | −0.00147 |
| | (0.000314) | (0.00132) |
| Post 2007*Ethanol Capacity | 0.000635*** | 0.00224*** |
| | (0.000241) | (0.000716) |
| Constant | 0.655*** | 0.609*** |
| | (0.0487) | (0.0651) |
| Observations | 2,083 | 5,883 |
| R-squared | 0.183 | 0.062 |
| Number of counties | 196 | 644 |

Note*: Heteroskedasticity robust (Huber/White) standard errors appear in parentheses. Additional controls include county population, year fixed effects and oil and gas production. Asterisks denote the following: ***= p<0.01, **= p<0.05, and *= p<0.1.*

### *Transaction Costs and Environmental Preferences Indicators*

We discussed the main results with individuals involved in the operation of the CRP program in Iowa, the number one corn-producing state in the United States where several ethanol plants are located. These individuals suggested that several factors largely related to the transaction costs of returning CRP land to production could be at play. In this section we discuss these factors and compare indicators of transactions costs and environmental preferences across counties with and without ethanol plants. While this analysis is suggestive, it is largely consistent with analysis of CRP policy changes and provides further evidence for whether local factors correlated with ethanol plant location could have counteracted any local price increase caused by ethanol plants.

We investigate the influence of transaction costs on re-enrollment, including (*a*) the prevalence of non-operating landowners who would have additional transaction costs over owner-operators, namely to find and manage new tenants; and (*b*) consistent with CCRP incentives and smaller tracts of land which would be more costly to convert, such as land on which it is difficult to operate large machinery. We also consider evidence for whether non-operating landowners may have had stronger preferences for environmental services/benefits. We test for correlation between factors that may have influenced landowner re-enrollment decisions and ethanol plant presence in table 5. We find evidence that landowners may have been more likely to re-enroll land in CRP in ethanol-intensive areas. For consistency, we focus on 2007 (an agricultural census year) in addition to 2008 (a presidential election year).

Rented land was more prevalent in ethanol-intensive areas, as indicated in table 5. A non-operating landowner considering whether or not to re-enroll their land into the CRP would face higher transaction costs for bringing land back into production, such as finding a tenant and negotiating lease terms. Given the presence of more rented land in ethanol-intensive areas, non-operating landowners may have decided that the transaction costs associated with finding and maintaining a relationship with a tenant outweighed the increased rental income.

**Table 5** Indicators of Transactions Costs and Environmental Preferences by Ethanol Plant Presence

| | No Plant | Plant | T-test p-value | Year |
|---|---|---|---|---|
| Average size of a CRP parcel (acres) | 38.4 | 25.4 | 0.0001 | 2007 |
| Shared rented farmland acres | 0.44 | 0.56 | 0 | 2007 |
| Average farm size (acres) | 674 | 516 | 0.026 | 2007 |
| Median farm size (acres) | 289 | 226 | 0.073 | 2007 |
| Share democrat votes | 41.6% | 43.9% | 0.034 | 2008 |

Note*: all variables are county-level.*

Parcel size relates not only to ease of entry into continuous CRP but also transaction costs associated with returning land to production. For example, equipment might be more difficult or costly to operate on small or odd-shaped parcels. We know ethanol plants tended to locate in counties with lower levels of total land in CRP, illustrated clearly in the map in figure 1. Counties with an ethanol plant in 2007 had an average parcel size more than 10 acres smaller than in counties without an ethanol plant (table 5). While average and median farm size are smaller in ethanol-intensive areas (table 5), the relationship is only weakly statistically significant.

We use county-level voting in the 2008 presidential election as a proxy for preferences for the environmental services or benefits provided by CRP. While local environmental preferences are difficult to measure, political outcomes are more widely available. While this is only a suggestive indicator, in general Democratic candidates have a stronger platform on conservation. We find higher levels of Democratic votes in the 2008 presidential election (Democratic share) in counties with an ethanol plant (table 5). This result is consistent with landowners in ethanol-intensive areas being more likely to value the environmental benefits of CRP and re-enroll their land in the program.

Higher transactions costs and preferences for environmental services combined with higher suitability for CCRP and REX may have been mutually reinforcing. A non-operating landowner with a small, odd-shaped parcel that gained satisfaction from the environmental benefits of CRP in an area with easier re-enrollment due to CCRP or REX, would have arguably had much stronger incentives for re-enrollment land into CRP. From our analysis, we know that many of these factors were more prevalent in ethanol-intensive areas. This is consistent with other research that has shown that transaction costs and program details play an important role in CRP participation decisions (Wachenheim et al. 2014). Our study confirms that these features were an important factor even during the recent commodity boom, which featured an extended period of historic levels of farm income.

### *Production Decisions and Pre-Trends*

In this section we test the general validity and comparability of our approach by testing for pre-trends and implementing our model for dependent variables used in other studies. In online supplementary appendix table A2, we use corn intensification as the dependent variable. Specifically, we use corn acres planted as a share of total corn and soybean acres planted to capture whether producers have shifted to more corn in their corn-soybean rotations. Arora et al. (2016) find evidence of reduced corn-soy rotation in the vicinity of ethanol plants in South Dakota. These effects of post-mandate ethanol capacity on corn intensification are statistically significant at the 1% level across most specifications. The magnitude is also economically significant. A 100 million gallon increase in ethanol capacity would have been associated with a one-percentage point increase in the share of corn out of total corn and soybean acres. This translates roughly into an additional 3,482 acres or 522,000 additional bushels of corn produced in 2008 if we assume average yields of 150 bushels per acre. We report similar but weakly statistically significant results for corn acres planted in online supplementary appendix table A3. These results for corn intensification and corn acreage confirm that our empirical strategy provides similar results to Motamed et al. (2016) and other studies that consider ethanol plant location and corn production. These findings also suggest that our results for CRP enrollment were driven by factors different than those driving other production decisions.

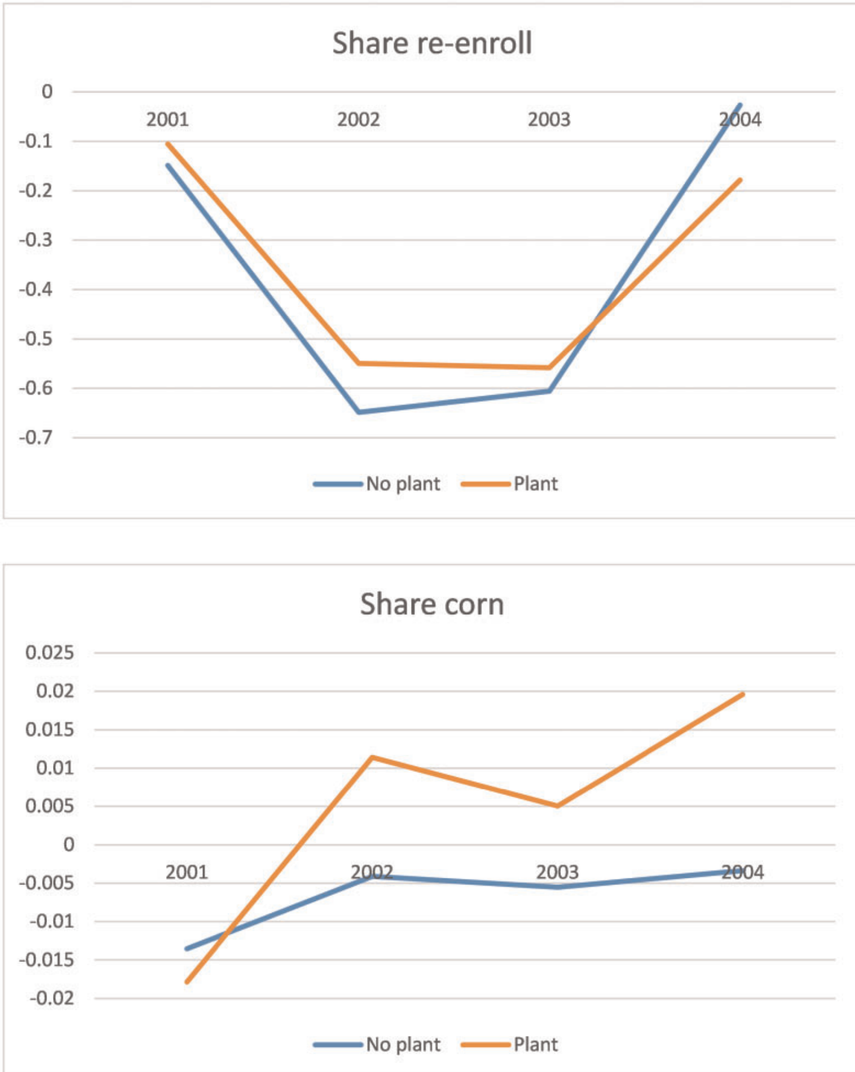
Consideration of pre-trends in CRP participation and corn production are also critical to evaluating the robustness of our empirical strategy, which makes strong identification assumptions. The year-ethanol plant coefficients from equation 3 are estimated for all of our dependent variables and reported for key variables in figure 2: the share of acres re-enrolled and share of corn. The charts illustrate how there was no apparent difference in trends for CRP re-enrollments, but pre-trends do appear to diverge for the share of corn. We conduct hypothesis tests for equality of growth trends in ethanol and non-ethanol counties, or whether $\gamma_1 = \gamma_2$. We cannot reject the hypothesis of similar growth ($\tau_t$) rates for the share of re-enrollment in ethanol and non-ethanol counties from 2001 to 2004. This strengthens the case for use of share re-enrollment as our key dependent variable. However, based on an F-test we reject the hypothesis of similar growth rates for corn share from 2002–2004. While not shown, we conduct the same test using total corn acres as a dependent variable and find the same result for the share of corn, rejecting the hypothesis of similar growth rates for 2002–2004.

Our main variable of interest does not violate the parallel trends assumption, but we find that it was violated for corn intensification and total corn acres. This suggests that ethanol plants were locating in counties that were experiencing higher growth in corn intensification and production before the mandate came into effect. Overall, this analysis finds no issue with our approach for CRP enrollment, and points to the CRP design changes discussed above as driving our results.

The lack of a parallel trend for corn intensification and production does raise some broader concerns for the literature on ethanol plant location and production decisions. If corn production was growing more rapidly in areas where ethanol plants were built or expanded, there may be a spurious correlation between the ethanol mandate and production decisions. Due to the time trend, this correlation might not be addressed by including location fixed effects or even detailed parcel characteristics. This could even be an issue in studies that use an instrumental variables approach, if the instrumental variable is time-invariant and interacted with time effects, such as in Motamed et al. (2016). Other studies such as Brown et al. (2014) and Blomendahl et al. (2011) do not directly address the issue of pre-trends.

**Figure 2** Time trends by ethanol status

*Note*: Year-ethanol plant coefficients ($\gamma_1$ and $\gamma_2$) from estimation of equation (3).




However, the triple differences approach of Towe and Tra (2013) provides an example of an approach that accounts for this source of bias. While not disproving the results of previous studies, this finding illustrates a common issue that should be addressed or discussed as a limitation of studies that consider ethanol plant location and various production decisions.

### *Robustness to Local Basis Shifts*

While our empirical model controls for national commodity price shifts, we cannot explicitly account for local prices changes that could potentially be related to CRP decisions. In addition to this data not being readily available, it would be difficult to account for the potential endogeneity of CRP re-enrollment decisions and local price shifts. While we do not know of any

**Table 6** Ethanol Capacity and CRP-reenrollment—Price Changes

| VARIABLES | (1) State prices | (2) 2006-09 only | (3) Below median rental increase | (4) Above median rental increase |
|---|---|---|---|---|
| Ethanol capacity | −9.67e-05 | 0.000538 | 0.000411 | −0.00118 |
| | (0.000601) | (0.000564) | (0.000378) | (0.00143) |
| Post 2007*Ethanol Capacity | 0.00131*** | 0.00102** | 0.00152*** | 0.000824*** |
| | (0.000235) | (0.000418) | (0.000392) | (0.000230) |
| Constant | 0.745** | 0.383 | 0.628*** | 0.673*** |
| | (0.355) | (0.243) | (0.0800) | (0.0431) |
| Observations | 7,177 | 2,827 | 4,385 | 3,581 |
| R-squared | 0.065 | 0.017 | 0.072 | 0.077 |
| Number of counties | 838 | 823 | 456 | 384 |

Note: *Heteroskedasticity robust (Huber/White) standard errors appear in parentheses. Additional controls include county population, year fixed effects and oil and gas production. Asterisks denote the following: ***= p<0.01, **= p<0.05, and *= p<0.1.*

other general local basis shifter other than ethanol capacity (i.e., Hart (2015)), for which we explicitly control, we cannot disprove the presence of other more idiosyncratic local basis shifts. We address this in a few ways. We first estimate a "naïve" regression with state-level corn prices, the most granular level that is publicly available. While our results do not change, in this specification (table 6) we do not fully control for more local price changes or address the potential endogeniety of state prices.

We next estimate our model from 2006–2009, with the perspective that this shorter period may be less likely to have experienced idiosyncratic local price changes. Even in this short period, we see similar results to our main specification, which also points to the overall robustness of our findings. While we cannot control for local price shifts, cropland cash rental rates are publicly available for our study area from 2008. Given that price shifts are reflected in cash rents but often with a short lag, the trend in cash rents from 2008–2014 provides an indicator of any relative local price changes that may have occurred post-mandate. We stratify our sample by above and below median rental rate trends and find results that are consistent with our main specification. While we cannot disprove that there are local price shifts that might be influencing our findings, the above discussed robustness checks suggest little evidence for this.

## Conclusion

Several studies find that ethanol plant location is associated with land use changes at both the extensive and intensive margins. This study considers the impact of ethanol plant capacity on CRP re-enrollment decisions before and after the ethanol mandate. We generally find no relationship between county-level CRP re-enrollment decisions and ethanol capacity when county and time fixed effects are included. We also find that less land in ethanol-intensive areas left the CRP after the mandate, which is likely explained by CRP design changes that occurred around the same time as the ethanol mandate.

Our finding of less CRP land leaving the program in ethanol-intensive areas is robust across a number of restrictive specifications, including the following: counties outside of Illinois and Iowa; counties with different cash rental rate growth, which proxies for local basis shifts; and in counties with different average soil quality. However, we find no effect in counties with larger or above-median CRP parcel size. This finding suggests that ethanol-intensive areas had CRP parcels that were more suitable for entry into continuous CRP and were less likely to leave the program during the crop price boom after the ethanol mandate went into effect. Parcel size may also be related to the environmental benefits score, which would have led to higher eligibility for REX, or automatic re-enrollment or extension contracts offered for parcels expiring between 2007–2010. Our findings are also consistent with higher transactions costs for transitioning CRP land to production and preferences for environmental benefits. While less definitive, indicators of these factors are more prevalent in counties with ethanol plants.

Given the broader importance of CRP policy changes and land use change (Hendricks and Er 2018), this study illustrates the importance of accounting for CRP policies in studies considering ethanol plant location. Our findings also suggest some limitations to studies using ethanol plant location. As a part of robustness checks for our empirical strategy, we found that while the parallel trends assumption is *not* violated for our main variable of interest—CRP re-enrollment—it is violated for corn intensification as well as total corn acreage. Counties with higher levels of ethanol production capacity had more rapid corn production growth on both the intensive and extensive margins before the ethanol mandate went into effect. This finding implies that caution is warranted when using ethanol plant location as an identification strategy when analyzing production decisions. Ethanol plant location is not only associated with access to transportation networks and higher levels of corn production, but also occurred in areas where corn production was growing more rapidly well before the mandate went into effect. Researchers analyzing the local impacts of ethanol plant location and the mandate may want to consider that local production trends, especially corn intensification, may violate identification assumptions implicit in such studies. This corn intensification trend may also be an interesting topic for future work.

Several million acres of CRP left the program after 2007, and at least some of this is most likely due to a biofuel policy-driven increase in agricultural commodity prices (de Gorter et al. 2015). While not disproving intensive or extensive land use change as a response to the ethanol mandate, these results support general price effects as drivers of land use change as opposed to ethanol plant location. CRP enrollment decisions have important implications for land use and hence agricultural and environmental policy, and CRP design changes appear to have affected behavior more than any local benefits of ethanol plants. In general, caution is warranted when interpreting results from the analysis of the impact of ethanol plant location on production decisions.

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## Supplementary Material

Supplementary material is available online at Applied Economic Perspectives and Policy online.

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