Impact of the Renewable Fuel Standard on Midwest Farmland Values

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Impact of the Renewable Fuel Standard on Midwest Farmland Values

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Abstract

We study the impact of the Renewable Fuel Standard (RFS) on farmland values in the US Midwest region. Using difference-in-differences estimation and the Census of Agriculture farmland value data, we show that before enacting the RFS, counties with high corn suitability and counties with low corn suitability had similar trends in values. After the passage of the RFS, farmland values in counties with high corn suitability grew faster than those in counties with low corn suitability. On average, the RFS policy leads to a $988 increase per acre in land value in counties with high corn suitability. The event study estimation shows a more significant impact of the RFS in 2012 and 2017 relative to 2007. The RFS has a much larger impact on farmland values in top corn-suitability counties.

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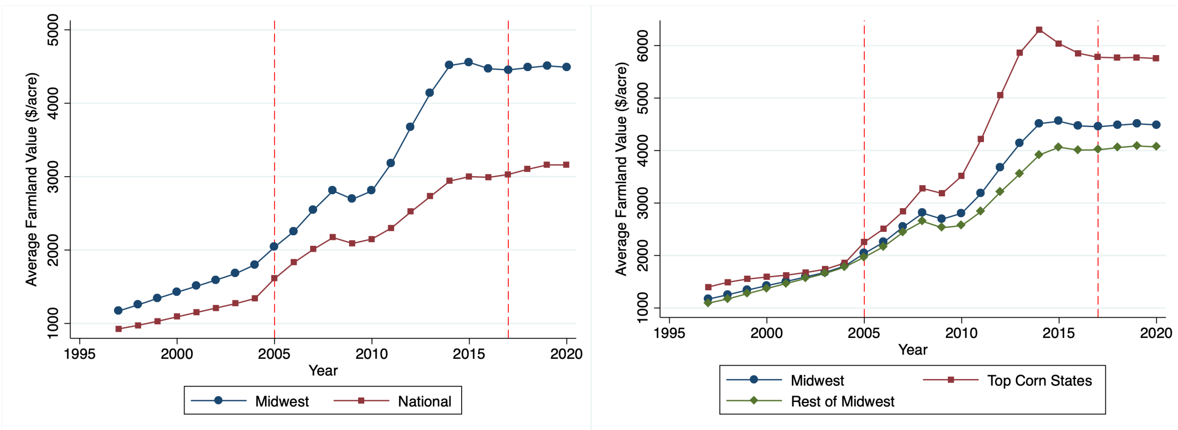
1 INTRODUCTION

In 2005, The Energy Policy Act established the first Renewable Fuel Standard (RFS), which requires the fuel used by US transportation to contain a minimum volume of renewable fuel. At first, the RFS set a 4 billion gallon biofuel requirement for 2006, which was estimated to reach 7.7 billion gallons by 2012. The RFS was expanded under the Energy Independence and Security Act of 2007, which increased the annual requirement and target of 15.2 billion gallons of biofuel by 2012.

The biofuel policy requires a minimum volume of renewable fuel to be blended in gasoline, leading to an increase in renewable fuel consumption. The primary renewable fuel that fulfills the RFS requirements is "conventional" biofuel (ethanol) made from corn starch. As ethanol annual requirements increase, more corn is used in ethanol production. In 2004, only 10.4% of the total corn supply (including inventory, US production, and import) or 11.2% of US corn production was used in ethanol production. In 2022, however, the demand for corn used in ethanol production increased and accounted for 34.2% of total corn supply and 38% of US corn production (USDA ERS Feed Grains: Yearbook Tables).

Figure 1: Farmland Values over time

(a) Midwest vs national level (b) Midwest region only



Note: This figure plots the average farmland value over time. Panel (a) compares the average farmland value between the Midwest region and the national level. In Panel (b) we show the average farmland value within the Midwest region. Top corn states include Illinois, Iowa, and Nebraska. Data are obtained from USDA National Agricultural Statistics Services.

As the US ethanol heavily relies on corn in its production, an increase in ethanol consumption leads to higher corn demand. The demand for corn is expected to increase along with the enactment and expansion of the RFS, leading to an increase in the price of corn. Higher prices lead to more areas planting corn and higher corn production. This increase in corn price would lead to an increment in farmland value. In fact, after the RFS mandate was passed, the differences in farmland value between the Midwest region and the other regions of the US increased substantially (see Panel (a) of Figure 1). Furthermore, within the Midwest region, the farmland value increased substantially more in states with high production of corn (Top Corn States in Panel (b) of Figure 1) than in states with little corn production. States with high production of corn are states with high corn suitability or high corn productivity. In contrast, states with low corn production are usually states with low corn suitability or low corn productivity. In this paper, we evaluate if the increase in farmland value is a causal effect of the RFS.

Many papers document the increase in corn production after the two RFS mandates in 2005 and 2007. Saavoss et al. (2021) document a stable trend in the total number of acres of corn planted before 2006, but the total number of acres planted corn increased substantially after 2006 when the 2005 RFS mandate was in effect. Lark, Salmon, and Gibbs (2015) find an increase in conversion from grasslands to croplands for corn planting after the RFS mandate. Similarly, Hendricks (2018) finds an increase of 2.8 million acres of cropland as a result of the RFS policy. Corn acreage increased about 24%, mainly in corn-belt states, along with the expansion of 2007 RFS (Smith 2019). Fatal and Thurman (2014) find an increase of 521 acres of corn planted in the county if a 100-million gallon ethanol plant is built. An increase in corn ethanol production also leads to land use changes such as the conversion of grassland to cropland and an increase in corn planted acres (Miao 2013; Searchinger et al. 2008; Wright and Wimberly 2013; Chen and Khanna 2018).

The rise in corn demand for ethanol production correlates with an increase in corn prices. Numerous studies have documented this phenomenon; for instance, Carter, Rausser, and Smith (2017) and Lark et al. (2022) both observe a 30% surge in corn prices attributable to the RFS mandate between 2006 and 2014. Condon, Klemick, and Wolverton (2015) find a long-run corn price increase of 2% - 3% for each billion gallons of corn ethanol production expansion using a meta-analysis approach on 19 published studies.

Rising corn prices typically coincide with enhanced expected annual returns, subsequently reflected in increased farmland values. While numerous studies explore the effects of RFS mandates on land use, corn production, and corn prices, fewer investigate its impact on farmland value. For instance, Towe and Tra (2013) observe a 15% - 28% rise in farmland values near new ethanol plants post-RFS, an effect absent pre-RFS. Similarly, Henderson and Gloy (2009) show evidence of a decrease in farmland values with distance from ethanol plants, with parcels located 50 miles away valued at $104 per acre less than those within 50 miles. Moreover, Park (2022) find a $109 per acre decrease in farmland value per one-mile increase from an ethanol plant, while Gardner and Sampson (2022) estimate an 8.8% price increase for parcels within 50 km from an ethanol plant compared to those further away. Additional studies such as Kropp and Peckham (2015) and Barkley, Aseete, and Sampson (2023) corroborate the rise in agricultural land values in counties where ethanol plants are located. However, current research primarily focuses on the impact of ethanol plants on nearby farmland values or those in counties hosting ethanol facilities.

In this paper, we estimate the impact of the RFS on Midwest farmland values. Given that over 90% of the US ethanol production comes from the Midwest region, the RFS's effects are expected to be more pronounced in this region. With ethanol production heavily reliant on corn, the RFS is likely to exert a greater influence on farmland values in counties where corn cultivation is prevalent or where agricultural land is highly corn-suitable. Using a difference-in-differences strategy, we analyze county-level data sourced from the Census of Agriculture. Our treatment group comprises counties where agricultural land is highly productive, which we call high corn suitability. The comparison group consists of counties where agricultural land has low productivity, which we call low corn suitability. We use the National Commodity Crop Productivity Index (NCCPI), which is uniformly available nationwide and standardized to define counties with high and low corn suitability (high and low productivity land). The key assumption underlying our identification strategy is the parallel trend assumption, positing that farmland value trends would have been similar before and after the RFS mandate in both high corn-suitability and low corn-suitability counties had the RFS policy not been implemented. We evaluate the validity of this assumption by estimating an event study specification.

We find that, on average, the RFS mandate resulted in a $988 per acre increase in agricultural land values in counties with high corn suitability. There is no difference in the trend in farmland values in counties with high and low corn suitability before the RFS; however, since the passage of the mandate, land values in counties with high corn suitability have grown much faster compared to counties with low corn suitability. The event study estimation shows no effects of the RFS on farmland values in 2007, where the target for ethanol production and consumption was much smaller, and the impacts of the mandate on farmland values were much larger in 2012 and 2017 when the ethanol target was approximately four times higher than 2007. We also show that the impact of the RFS policy is much more pronounced in top corn suitability counties where land values in top corn suitability counties increase by $1,671 per acre after the RFS, and the event study estimation shows the impact of the policy in 2012 and 2017. Higher corn prices, an increase in demand for farmland in corn suitability counties, and an increase in conversion of pastureland are possible explanations for this increase in farmland values in corn suitability counties.

Our study contributes to the literature in several significant ways. First, we quantify the impact of the RFS on agricultural land across the twelve states in the Midwest region, a key area for US corn production. Unlike prior research limited to assessing the RFS's effects on farmland values near ethanol plants or in counties hosting such facilities, we demonstrate its broader impact on agricultural land values in counties where agricultural land is corn-suitable. Second, by elucidating the policy's influence on farmland values, we offer a potential mechanism to explain the rapid increase in farmland values observed in the Midwest region over the two decades spanning 1997 to 2017.

The remainder of the paper is structured as follows. Section 2 presents the RFS policy background. Section 3 describes the data. Section 4 outlines the empirical estimation strategy. Section 5 presents the estimation results, sensitivity analysis and robustness check. We conclude in Section 6.

2 Renewable Fuel Standard Background

Although the RFS plays an important role in the development and growth of the U.S. ethanol industry, the production and consumption of ethanol in the U.S. are not new. Before the RFS mandate, several policies subsidized and supported the use of ethanol in the fuel. The Energy Tax of 1978 defined "gasohol" as fuel that consists of at least 10% of ethanol and the $0.40 per gallon of ethanol tax exemption. The Energy Security Act of 1980 offered small ethanol producers who produce less than 1 million gallons annually insured loans that could cover up to 90% of the ethanol plant construction costs. The Crude Oil Windfall Profit Tax Act of 1980 extended the exemption of ethanol from gasoline excise tax. Since the 1980s till today, there have been many policies that subsidy ethanol such as exemption on gasoline excise tax range between $0.40-$0.60 per gallon (Johnson et al. 2021; Tyner 2015; Solomon, Barnes, and Halvorsen 2007; Kesan, Yang, and Peres 2017).

In conjunction with efforts to mitigate greenhouse gas emissions and reduce reliance on imported oil, the Renewable Fuel Standard (RFS) mandate was established under the Energy Policy Act of 2005. This mandate necessitates a minimum volume of renewable fuel blending in U.S. transportation fuel. Initially, the RFS aimed for 4 billion gallons of renewable fuel to be blended into gasoline in 2006, with this target gradually increasing to 7.7 billion gallons by 2012. Subsequently, the RFS underwent expansion under the Energy Independence and Security Act of 2007 (EISA), which raised the minimum annual renewable fuel blending requirements. By 2012, this requirement escalated to 15.2 billion gallons and reached 36 billion gallons by 2022 (Bracmort 2018; Duffield, Xiarchos, and Halbrock 2008). The Environmental Protection Agency (EPA) administers and monitors RFS compliance, utilizing the Renewable Identification Number (RIN) system, assigning a RIN to each gallon of renewable fuel. The volume obligations for oil refiners, gasoline, and diesel importers are determined as a percentage of their petroleum product sales.

The RFS comprises four categories of renewable fuel, and each is assigned with annual volume targets. The four categories include cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel. Total renewable fuel includes conventional biofuel and advanced biofuel. As of 2017, the requirements are mainly fulfilled by conventional biofuel or ethanol, which is made from corn starch.

3 Data and Descriptive Statistics

The main data source comes from the Census of Agriculture conducted by the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) from 1997 to 2017 with a 5-year interval. The Census of Agriculture includes information on land use, income, characteristics of producers, production and sale activities, and other farm-related items. The Census of Agriculture is the only comprehensive source of agricultural data with information on US farmland at the county level.

The outcome variable of interest is the US farmland value at the county level. Farmers report the land value based on their opinion about the market value of the parcel they operate as of December 31 of each census year. Other information from Census of Agriculture data includes acres of corn harvested, government payment, and total cropland area. Acres of corn harvested are at the county level, which we use to determine whether a county produces corn or not. Government payments include payments that were paid directly to farm producers, such as payments received from the

Table 1: Summary Statistics

	Mean	SD	Min	Max
Land Value (thousands/acre)	2.85	2.15	0.15	26.65
Total Cropland (thousand acres)	219.69	152.54	0.18	1,085.43
Total Ag Land (thousand acres)	325.61	266.04	0.21	3,853.47
Percent Cropland	70.62	20.67	2.40	100.00
Corn Planted (%)	22.09	16.94	0.00	71.79
Gov Payment (millions)	3.90	2.98	0.00	25.65
Annual Return (millions)	5.06	22.07	-111.02	389.85
Population Density (persons/square mile)	115.29	334.52	0.47	5,674.89
NCCPI	0.53	0.15	0.14	0.89
Observations	5,240			

Note: These summary statistics are obtained with our final database formed as a balanced panel of counties located across twelve states in the Midwest region of the US, in the period 1997-2017.

Conservation Reserve Program (CRP), Farmable Wetlands Program (FWP), Wetland Reserve Program, and Conservation Reserve Enhancement Program (CREP). Government payments also include disaster payments, loan deficiency payments, other conservation programs, Agriculture Risk Coverage, and Price Loss Coverage.

Other data include county population data from the Census Population and Housing Unit Estimates dataset, which provides annual population estimates in all US counties.[1] Population density is calculated by dividing a county's total population by the total land area in that county. The total land area is obtained from the 2010 TIGER/-Line Shapefile.[2] Soil quality is measured by the National Commodity Crop Productivity Index (NCCPI), sourced from the Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic Database (gSSURGO). The NCCPI gauges the inherent capacity for growing nonirrigated commodity crops such as corn, soybean, small

1. The Bureau of Economics Analysis also has estimated data on county population; however, there are many missing data for county population for the earlier years, such as 1997 and 2002. Thus, we use the Census's estimated population at the county level.

2. We assume the total land area at each county would not change much over time. The land area in TIGER/Line Shapefile is square kilometers, which we converted to square miles.

grain, and cotton, drawing on soil survey data available in counties cultivating commodity crops. Unlike other soil quality metrics like the Corn Rating System, confined to Iowa, or the Crop Productivity Index (CPI), potentially inconsistent across time and political boundaries, the NCCPI is uniformly available nationwide and standardized. The NCCPI ranges from 0.01 to 1, with 1 indicating the most favorable soil type for commodity production.[3] Net farm income is sourced from the Bureau of Economic Analysis (BEA) farm income and expenses table at the county level, defined as cash receipts minus production expenses plus the value of inventory change.

We construct a balanced panel for twelve states in the Midwest region from 1997-2017. Our final sample includes 5,240 observations of 1,048 counties in 5 census years across 12 states in the Midwest region. We excluded six counties due to missing data on agricultural land and total cropland.[4] Table 1 reports the summary statistics of the dependent and key explanatory variables of the full sample. On average, the value of agricultural land is around \$2,850/acre. A county has about 325,610 acres of agricultural land, with cropland accounting for about 71% of the total agricultural land. Only 22% of total agricultural land is planted corn, on average.

Ethanol expansion after the RFS mandate has led to an increase in corn production and corn prices, as many papers in the literature documented. Higher demand for ethanol has led to higher demand for corn. An increase in corn price and the expansion in corn production will likely have a positive impact on farm annual return, which is capitalized in farmland value. The mandate will mostly affect land values in counties where corn was produced relative to counties with no or little corn production. Table 2 reports the summary statistics for groups of counties with high and low corn suitability before and after the RFS was imposed. Counties with low corn suitability are the counties in the bottom 10th percentile of soil quality counties based on NCCPI in the Midwest region. The cropland in these counties are low productivity land and these counties produce little corn. In fact, their harvested area only accounts for 2.33%

3. More details about the NCCPI can be found at: https://www.nrcs.usda.gov
4. Three counties in Wisconsin, two counties in North Dakota, and one county in Michigan)

Table 2: Summary Statistics: High and Low Corn Suitability Counties

	High Suitability		Low Suitability	
	Before	After	Before	After
Land Value (thousands/acre)	1.67	3.92	0.82	1.70
	(1.18)	(2.22)	(0.81)	(1.28)
Total Cropland (thousand acres)	232.21	222.45	168.15	154.36
	(146.19)	(150.95)	(173.43)	(166.23)
Total Ag Land (thousand acres)	308.81	300.83	538.04	507.06
	(189.36)	(191.81)	(596.31)	(572.03)
Percent Cropland	75.03	73.02	42.65	41.26
	(15.98)	(19.31)	(19.80)	(20.56)
Corn Planted (%)	21.47	26.00	2.33	3.88
	(15.59)	(16.85)	(3.63)	(5.10)
Gov Payment (millions)	3.42	4.58	1.51	2.25
	(2.29)	(3.26)	(1.67)	(2.71)
Annual Return (millions)	2.16	8.02	-3.22	1.36
	(13.38)	(27.21)	(6.54)	(13.03)
Population Density (persons/square mile)	122.27	129.04	15.91	16.34
	(347.27)	(353.23)	(22.26)	(24.42)
NCCPI	0.57	0.57	0.25	0.25
	(0.12)	(0.12)	(0.04)	(0.04)
Observations	1,886	2,829	210	315

Note: Corn Planted is the percentage of agricultural land that is used to plant corn in a county. Low corn suitability is the comparison group that includes counties in the bottom 10 percentile of the distribution of counties that have the lowest soil quality. The treatment group includes the remaining counties.

- 3.88% of their total agricultural land. Counties with high corn suitability are the remaining counties. Hereafter, we refer to counties with low corn suitability as counties in the bottom 10th percentile of the distribution of counties that their agricultural land is low productivity. Counties with high corn suitability have smaller total agricultural land. However, most of the farmland is cropland, which accounts for approximately 75% of total farmland. The corn suitability group was more dense in population density compared to the low corn suitability group. Farmland is more valuable than the group of counties with low corn suitability. Figure A.1 in the Appendix shows the location of counties in treatment and comparison groups.

4 Empirical Strategy

We study the impact of the Renewable Fuel Standard mandate on the Midwest farmland value. Along with concerns about energy independence, pollution, and greenhouse gas emissions, The Energy Policy Act established the RFS in 2005, requiring a minimum volume of renewable fuel blended in the U.S. transportation fuel. The extensive expansion of ethanol production after the RFS has increased corn prices and corn production. Carter, Rausser, and Smith (2017) find a 30% increase in corn prices between 2006 and 2014 due to the RFS mandate. The authors also document the expansion of ethanol production exacerbates the impacts of the 2012 drought on corn prices. Without the mandate and ethanol expansion, corn prices in 2012 would have been 40% lower. Similarly, Lark et al. (2022) find that corn prices increase by 30% and corn production increase by 8.7% due to RFS. Higher corn prices result in higher expectations of annual return, which will positively affect farmland value. Therefore, land values in counties with higher acres of corn planted or where corn production is highly productive would be affected more due to the enactment of the RFS mandate.

To study the impacts of the Renewable Fuel Standard mandate on the US farmland value, we use a difference-in-differences strategy. The comparison group includes low corn suitability counties, and the treatment group includes high corn suitability counties. The key identifying assumption is the parallel trend assumption, which suggests that the differences in farmland value before and after the RFS mandate would have been the same in counties with high and low corn suitability had the RFS mandate not been implemented. To estimate the impact of RFS on farmland value, we estimate Equation 1 as follows:

$$LandValue_{ijt} = \alpha + \beta Treatment_j \times AfterRFS_t + \boldsymbol{X_{ijt}\theta} + \mu_t + \mu_i + \mu_{st} + \epsilon_{ijt} \qquad (1)$$

The outcome variable is the land value of county i in group j at year t. The variable $Treatment_j$ is a dummy variable that takes values of 1 if county i is a high corn suitability and 0 otherwise. The variable $AfterRFS_t$ is a dummy equal to 1 if we observe the county after the year 2005, when the first RFS passed, and 0 otherwise.

In our main specification we include a vector of control variables, $\boldsymbol{X_{ijt}}$, such as government payment, net farm income, and population density. Government payment is an important factor that affects farmland values as documented in many studies (Vyn et al. 2012; Mishra, Moss, and Erickson 2009; Latruffe and Le Mouël 2009). Net farm income is an important determinant of land value. Higher net farm income is expected to have positive impacts on farmland values. Population density is also a driver of land value.

Notice that counties with higher population density are more likely to have higher pressure on urbanization, which likely affects farmland values. We include county fixed effects, μ_i, which control for all time-invariant county characteristics such as topography, and soil quality.[5] Year fixed effects, μ_t, are included to control for factors that affect agricultural land values over time across the Midwest region such as inflation, improvement in technology, interest rate, etc. In addition, we control for state trends, μ_{st}, to avoid incorrectly accounting for the inherent increase in farmland values due to some states growing faster for factors not related to the RFS.

The key identifying assumption states that, in the absence of the Renewable Fuel Standard mandate, differences in land value before and after the policy implementation, would have been the same in the counties with high corn suitability and counties with low corn suitability. To assess the validity of the parallel trend assumption, we estimate the event study coefficient β_y in Equation 2:

$$LandValue_{ijt} = \alpha + \sum_{\substack{y=1997 \\ y\neq 2002}}^{2017} \beta_y 1[t = y] \times Treatment_j + \mathbf{X_{ijt}}\boldsymbol{\theta} + \mu_t + \mu_i + \mu_{st} + \epsilon_{ijt}, \quad (2)$$

5. Soil quality is measured by NCCPI, which is unchanged over time; therefore, by including county fixed effects we take into account this variable.

where $y \in \{1997, 2007, 2012, 2017\}$. The omitted year is 2002, which corresponds to the first observed year before the RFS mandate was enacted. The parameters of interest are β_y. The parallel trend assumption is supported if β_y equals zero for the year before the policy went into effect.

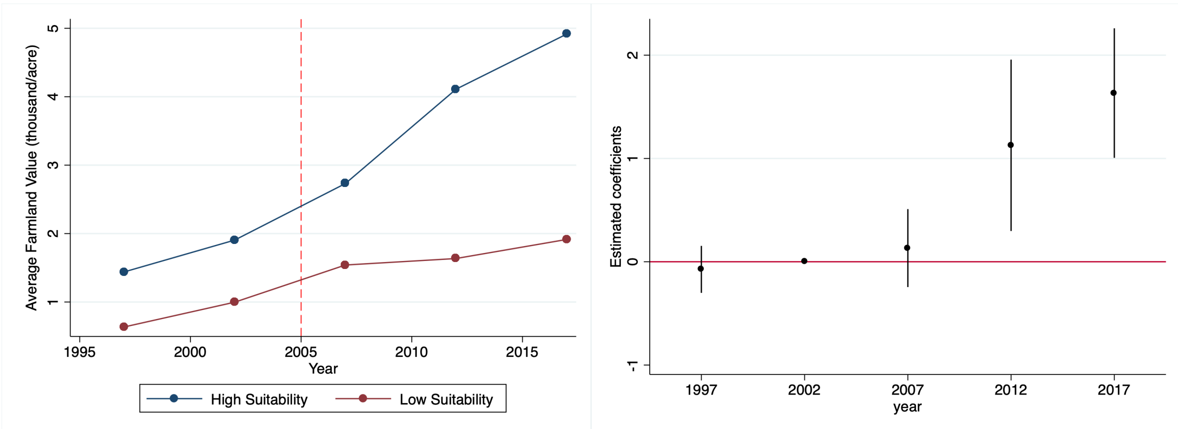
5 RESULTS

5.1 MAIN RESULTS: FULL SAMPLE

Table 3 reports the estimation coefficients corresponding to Equation 1 of the impact of the RFS mandate on farmland values. The treatment group includes counties with high corn suitability. The comparison group includes counties without corn production.

Figure 2: Event Study, Effects of Renewable Fuel Standard on Midwest Farmland Values.

(a) Average Land Value (b) Event Study Estimate



Note: These figures plot average farmland value of the treatment and comparison groups in panel (a) and the event study estimate for the effect of Renewable Fuel Standard mandate on the Midwest farmland values in panel (b). The coefficients are estimated from Equation 2. The dots represent the point estimates, and the whiskers represent the 95% confidence intervals.

In column 1 of Table 3, we include county, year, and state by year fixed effects without including any other control variables. We add annual return as a control variable in column 2 and population density as an additional control variable in column 3. In column 4, we add government payment into our regression. The coefficient of interest is the one associated to the interaction term $Treatment \times AfterRFS$, showing the

Table 3: Effects of Renewable Fuel Standard on Midwest Farmland Values

	(1) Land Value	(2) Land Value	(3) Land Value	(4) Land Value
Treatment × *AfterRFS*	1.293***	1.229***	1.073**	0.988**
	(0.267)	(0.268)	(0.279)	(0.254)
Annual Return (millions)		0.007*	0.007*	0.007*
		(0.003)	(0.003)	(0.003)
Population Density (persons/square mile)			0.002***	0.002***
			(0.000)	(0.000)
Gov Payment (millions)				0.048
				(0.028)
Observations	5,240	5,240	5,240	5,240
R-squared	0.853	0.856	0.885	0.887

Note: Standard errors clustered at the state level are in parentheses. The outcome variable is the agricultural land value (thousands/acre) in county i in group j at year t. The treatment group includes counties with high corn suitability. The comparison group includes counties with low corn suitability. The parameters of interest are the coefficients of the interaction term, *Treatment* × *AfterRFS*. All the specifications include county, year, and state × year fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

casual impact of the RFS mandate on Midwest farmland values, which range from 0.988-1.293. Our findings suggest that, after the enactment of the mandate, agricultural land values in counties with high corn suitability increased by $988-$1,293 per acre. Kropp and Peckham (2015) find that farmland values increase by $576.65 per acre if the county has an ethanol plant, while increase by $1,356.89 per acre if the county has two ethanol plants. Given that most ethanol plants are located in the Midwest region because of the proximity to corn production, our results align with findings from Kropp and Peckham (2015). Barkley, Aseete, and Sampson (2023) find a smaller effect of new ethanol plant construction on nearby farmland values in the Great Plains region, where the authors find an $85 per acre increase in land value in the county where ethanol plant located and $75 per acre increase in land value in adjacent counties. Similarly, Henderson and Gloy (2009) find a decrease in farmland value as the distance to ethanol plant increases.

Figure 2a plots the average agricultural land values for high corn suitability and low corn suitability counties from 1997-2017. Agricultural land is more valuable in counties with high corn suitability than those with low corn suitability. Before the RFS, farmland values between the treatment and comparison groups have similar trends. After the RFS, farmland values in counties with high corn suitability increased faster than in counties with low corn suitability. Figure 2b plots the event study coefficients estimation corresponding to Equation 2. Before the enactment of the RFS, there is no difference in the change of land values in counties with high corn suitability and counties low corn suitability. After the RFS went into effect, land values in counties with high corn suitability increased faster than those in the low corn suitability counties. The effect of the RFS on farmland values is stronger in 2012 and 2017 compared to 2007, given that the requirement of ethanol to be blended in gasoline is almost four times higher in 2012 and 2017 relative to 2007.

5.2 Top Corn Suitability Counties

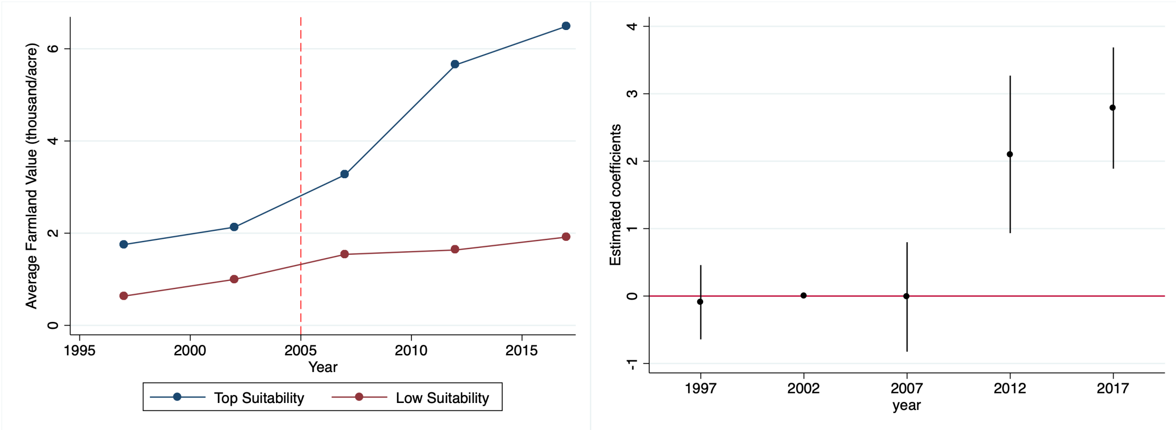
As the RFS creates a new market for corn leading to an increase in demand for corn and an increase in corn price, the RFS will have an impact on land value where corn is produced relative to places where little or no corn is produced. Corn is more likely to grow in counties where land is highly productive or high corn suitability. In the previous section, we show that RFS leads to a $988 increase per acre in counties with high corn suitability. In this section, we estimate the impact of the RFS on land values in counties with the top quartile in the distribution of soil quality. Our comparison group includes counties low corn suitability.

Table A.1 in the Appendix reports the summary statistics for top and bottom corn production counties before and after the RFS. While almost all of the agricultural land in top corn production counties is cropland, and half of the agricultural land is used to plant corn, counties in bottom corn production barely planted any corn. Soil quality measures by NCCPI in top corn production are almost three times than those in bottom corn suitability counties.

Table 4 reports the estimation coefficients corresponding to Equation 1 with the treatment group including counties in the top 25% of counties based on soil quality,

Figure 3: Event Study, Effects of Renewable Fuel Standard on Top Corn Suitability Counties.

(a) Average Land Value (b) Event Study Estimate



Note: These figures plot average farmland value of the treatment and comparison groups in panel (a) and the event study estimate for the effect of Renewable Fuel Standard mandate on the Midwest farmland values in panel (b). The coefficients are estimated from Equation 2. The dots represent the point estimates, and the whiskers represent the 95% confidence intervals.

Table 4: Effects of RFS on Midwest Top Corn Suitability Counties

	(1) Land Value	(2) Land Value	(3) Land Value	(4) Land Value
Treatment $\times$ *AfterRFS*	1.918***	1.755***	1.698**	1.671**
	(0.140)	(0.387)	(0.393)	(0.377)
Annual Return (millions)		0.007*	0.008*	0.008*
		(0.003)	(0.003)	(0.003)
Population Density (persons/square mile)			0.003***	0.003***
			(0.000)	(0.000)
Gov Payment (millions)				0.011
				(0.011)
Observations	1,835	1,835	1,835	1,835
R-squared	0.957	0.959	0.961	0.961

Note: Standard errors clustered at the state level are in parentheses. The outcome variable is the agricultural land value (thousands/acre) in county i in group j at year t. The treatment group includes counties that are in the top quartile of the corn suitability distribution. The comparison group includes counties with low corn suitability. The parameters of interest are the coefficients of the interaction term, *Treatment* $\times$ *AfterRFS*. All the specifications include county, year, and state $\times$ year fixed effects.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

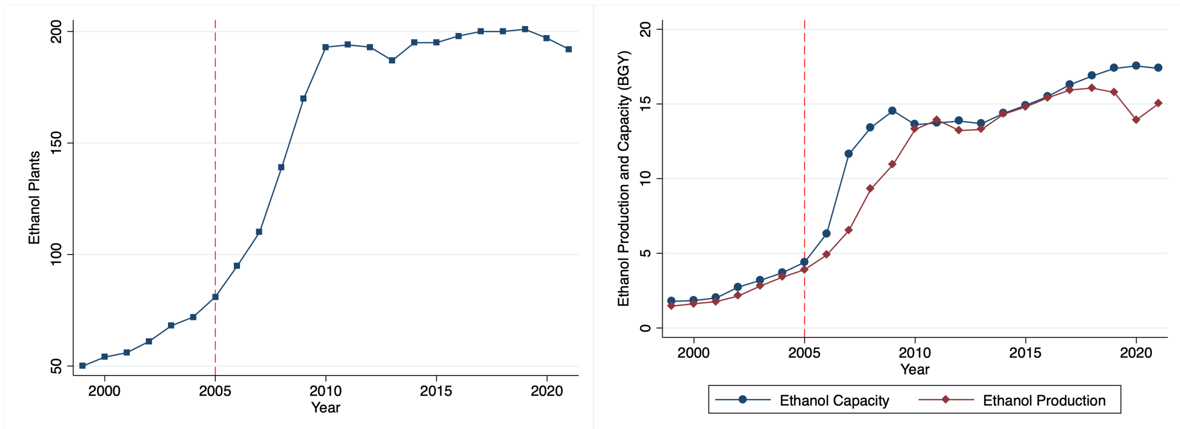
and the comparison group is counties low corn suitability in the Midwest region. As expected, the RFS has a much larger impact on top corn suitability counties. On average, agricultural land values in top corn suitability counties increase by $1,671-$1,918 per acre after the RFS. Agricultural land is more valuable in top corn suitability counties than in bottom corn suitability counties. Before the RFS, farmland values in top and bottom corn suitability counties followed the same trends; however, the gap between the agricultural land values in top and bottom corn suitability counties became much larger after the RFS mandate, as shown in Figure 3a. The event study graph, Figure 3b, shows a much larger impact of the RFS in 2012 and 2017, consistent with the findings in the main results.

5.3 RFS Mandate and Ethanol Production

There were 200 ethanol plants in the U.S. as of January 1, 2017, with a total capacity of 15,505 (MMgal/year).[6] Figure 4a plots numbers of ethanol plants from 1999-2020. The number of ethanol plants increased by 178% from 74 plants in 2004 before the RFS enactment to 200 plants in 2017. Along with the construction and expansion of ethanol plants, ethanol production capacity, and ethanol production increased rapidly after the policy in 2005, as shown in Figure 4b.

Figure 4: Ethanol Plants, Production Capacity, and Production.

(a) Ethanol Plants (b) Ethanol Production Capacity and Production



Source: U.S. Energy Information Administration (EIA), U.S. Fuel Ethanol Plant Production Capacity (eia.gov/petroleum/ethanolcapacity/index.php) and EIA Monthly Energy Review, Table 10.3 (eia.gov/totalenergy/data/monthly/#renewable).

More than 90% of the U.S. ethanol production is in the Midwest region, where much of the corn is produced. Three states, Iowa, Nebraska, and Illinois, accounted for 50%

6. Source: Form EIA-819, Monthly Report of Biofuels, Fuels from Non-Biogenic Wastes, Fuel Oxygenates, Isooctane, and Isooctene.
Link: https://www.eia.gov/petroleum/ethanolcapacity/archive/2017/index.php

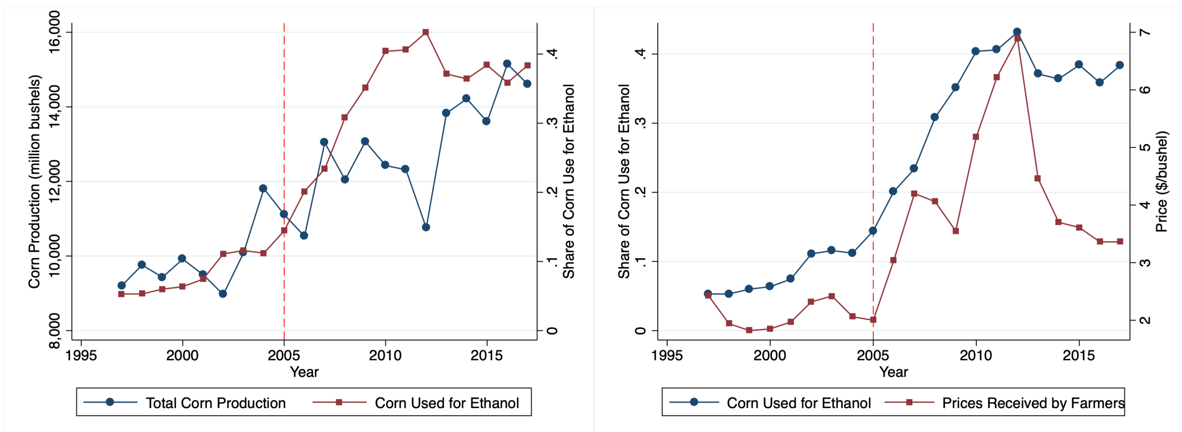
of the U.S. annual ethanol production in 2019 (U.S. Energy Information Administration, State Energy Data System as of July 1, 2021.) Therefore, the impact of the RFS will be more pronounced in the Midwest region. In addition, the requirements in the RFS are mainly met by ethanol, which is made from corn; the RFS would have larger effects in counties where corn is highly productive. As shown in the previous section, we find that land values in counties where corn is highly productive grow faster than those in counties where corn is not productive to grow after the policy. The impact of the policy is much larger in top corn-suitability counties.

5.4 Corn Used in Ethanol Production and Corn Prices

The RFS requires a minimum volume of ethanol to be blended in gasoline annually, and this minimum requirement increases gradually. As more ethanol is consumed, ethanol production increases. The US relies heavily on corn in ethanol production. Demand for corn used in ethanol production increases along with the increase in ethanol production. All else constant, higher demand for corn leads to higher corn prices and higher expected annual returns. Land values in counties where corn is highly productive are expected to increase faster than in counties where corn is not productive due to higher corn prices and expected annual returns.

Figure 5: Total Corn Production, Ethanol Use, and Corn Price Received by Farmer.

(a) Corn Production and Ethanol Use | (b) Ethanol Use and Corn Price



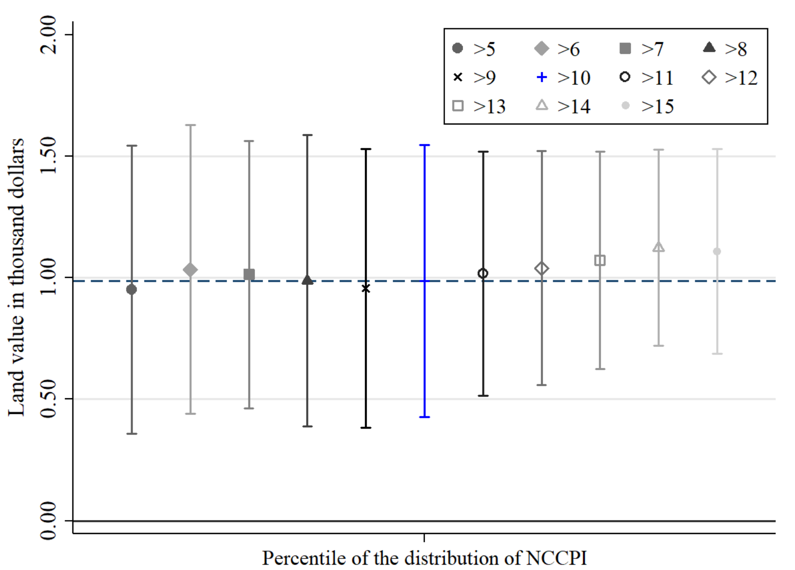
Source: Corn production and corn prices are obtained from USDA, Economic Research Service; USDA, National Agricultural Statistics Service. Updated: September 2022. Corn use for ethanol is obtained from United States Department of Agriculture, Economic Research Service, Feed Grains Yearbook.

Figure 5a shows a significant increase in corn used for ethanol production after RFS. In 2004, about 11.2% of total US corn production was used in ethanol production. In 2022, 38% of US corn production was used in ethanol production. Figure 5b shows an increase in corn prices immediately after the RFS passed in 2005. The price of corn peaked at around $7 in 2012 due to the severe drought that affected corn yield, as shown in Figure 5a. After 2012, corn prices fell but remained above the pre-RFS policy level. Higher corn prices after the RFS mandate are not due to the short supply in corn production but mainly due to the increase in corn demand. Carter, Rausser, and Smith (2017) find that corn prices increase by 30% between 2006 and 2014 as the results of the RFS. Condon, Klemick, and Wolverton (2015) do a meta-analysis on 19 published studies and find that long-run corn prices increase by 2% - 3% for each billion gallons of corn ethanol production expansion. Expectations of higher long-run corn prices and higher annual returns as results of RFS are factors that explain our findings of faster growth in land values in counties where corn is highly suitable or highly productive. In addition, the increase in farmland prices could be driven by an increase in demand for farmlands in corn-productive counties, given that the supply of farmland is limited. It is possible that there is an increase in demand for farmlands in counties where corn is highly suitable from investors and farmers due to expected higher annual returns, which led to our findings of faster growth farmland values in counties where corn is suitable.

5.5 Robustness Checks

In this section, we offer two robustness checks of our main results. First, we provide a sensitivity analysis on the threshold that defines the treatment and comparison groups. We demonstrate the robustness of our findings to variations in the treatment variable. Our primary results were based on categorizing counties as high corn suitability counties if they ranked at or above the 10th percentile of the distribution of soil quality. In this sensitivity analysis, we consider different "treatment thresholds" starting at the 5th percentile and finishing at the 15th percentile.

Figure 6: Sensitivity Analysis



Note: Each point estimate presented in this figure corresponds to an individual regression. We use Equation 1 across all regressions, with the sole distinction being in the definition of the treatment variable. Specifically, we vary the treatment threshold from the 5th to the 15th percentile. Confidence intervals at 95% level.

Each point estimate presented in Figure 6 corresponds to an individual regression. We maintain the use of Equation 1 across all regressions, with the sole distinction being in the definition of the treatment variable. Specifically, we vary the treatment threshold from the 5th to the 15th percentile. Our estimate remains robust around the initially proposed 10th percentile threshold. Moreover, while various treatment thresholds may yield different point estimates, all remain statistically significant. Thus, our estimate exhibits robustness not only in terms of statistical magnitude but also in terms of statistical significance.

Second, we offer an additional robustness check by gradually excluding Iowa, Illinois, and Nebraska. As shown in Figure 1b, farmland values in these states increased at a higher rate than the rest of Midwest states after the RFS. We were worried that the findings in our main result were mainly driven by the these top corn growing states. We gradually exclude Iowa, Illinois, and Nebraska, redo our analysis as Equation 1, and report the estimation in Table 5. In Column 1, Table 5, we excluded Iowa. Column 2, we excluded both Iowa and Illinois. We excluded Iowa, Illinois, and Nebraska in

Table 5: Robustness Check: Effect of Renewable Fuel Standard on Farmland Values

	(1) Land Value	(2) Land Value	(3) Land Value
Treatment $\times$ *AfterRFS*	1.002**	1.022**	0.781**
	(0.247)	(0.247)	(0.219)
Annual Return (millions)	0.003	0.003	0.004
	(0.002)	(0.003)	(0.003)
Population Density	0.002***	0.002***	0.002***
(persons/square mile)	(0.000)	(0.000)	(0.000)
Gov Payment (millions)	0.043	0.054	0.042
	(0.031)	(0.029)	(0.030)
Observations	4,745	4,235	3,770
R-squared	0.880	0.879	0.885

Note: Standard errors clustered at the state level are in parentheses. The outcome variable is the agricultural land value (thousands/acre) in county i in group j at year t. The treatment group includes counties that high corn suitability. In Column 1, we excluded Iowa. In Column 2, we excluded both Iowa and Illinois. We excluded Iowa, Illinois, and Nebraska in Column 3. The comparison group includes counties with low corn suitability. The parameters of interest are the coefficients of the interaction term, *Treatment* $\times$ *AfterRFS*. All the specifications include county, year, and state $\times$ year fixed effects.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Column 3. The results remain strong and robust, which suggests these states do not drive our findings.

6 Conclusions

This paper aims to study the impact of the RFS on Midwest farmland values using data from the Census of Agriculture 1997-2017. More than 90% of US annual ethanol production is located in the Midwest areas, where corn is produced. Hence, as for the external validity of our results, we expect that the impact of the policy is more pronounced in the Midwest region. To achieve causal identification, we leverage the implementation of the RFS in a difference-in-differences research design. As the treatment group, we consider counties where its corn suitability based on soil quality, while the comparison group includes counties with low corn suitability based on soil quality. We provide suggestive evidence on the validity of our identifying assumption, suggesting that the differences in farmland values, before and after the RFS, would have been the same in counties with high and low corn suitability had this policy not been implemented.

Our results suggest that the RFS mandate increased farmland values by $988 per acre. Furthermore, our event study estimation shows stronger effects of the RFS in 2012 and 2017 than in 2007, which is consistent with the increase in the 2012 change of ethanol usage requirements to produce fuels. Indeed, the impact of the RFS is more significant in top corn suitability counties. On average, farmland values in top corn production experienced approximately $1,671 increase per acre after the RFS, and the effect of the RFS on farmland values in those counties is much larger in 2012 and 2017, and larger compared to high corn suitability counties. .

Unlike prior studies, which primarily concentrate on the impacts of the RFS on farmland values near ethanol plants, we offer a potential mechanism elucidating the swift escalation in farmland values across the Midwest, a major hub for US corn production. Specifically, our analysis indicates that the principal driver of the effect on farmland values was the corn price from the policy's inception until 2012. Nevertheless, we document that the RFS continued increasing the farmland value. These findings suggest that in recent years, the mechanisms by which the RFS influences farmland values are through the expectation of higher annual returns through the increase in corn prices and possibly an increase in farmland demand.

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Appendix

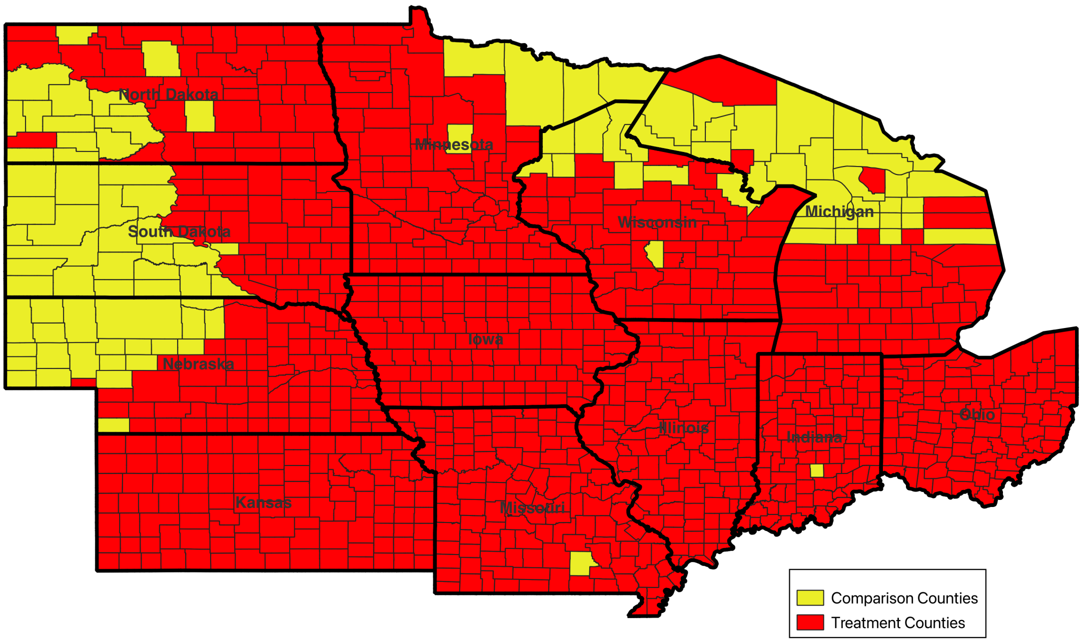
A Supplemental Tables and Figures

Table A.1: Summary Statistics: Top and Bottom Corn Suitability Counties

	Top Suitability		Low Suitability	
	Before	After	Before	After
Land Value (thousands/acre)	1.94	5.13	0.82	1.70
	(0.74)	(2.11)	(0.81)	(1.28)
Total Cropland (thousand acres)	267.61	260.46	168.15	154.36
	(98.48)	(102.37)	(173.43)	(166.23)
Total Ag Land (thousand acres)	313.77	307.18	538.04	507.06
	(107.69)	(108.68)	(596.31)	(572.03)
Percent Cropland	85.21	84.49	42.65	41.26
	(9.23)	(11.72)	(19.80)	(20.56)
Corn Planted (%)	34.26	40.06	2.33	3.88
	(13.25)	(14.59)	(3.63)	(5.10)
Gov Payment (millions)	4.63	6.11	1.51	2.25
	(1.88)	(2.70)	(1.67)	(2.71)
Annual Return (millions)	8.11	16.60	-3.22	1.36
	(15.42)	(32.74)	(6.54)	(13.03)
Population Density (persons/square mile)	79.71	85.06	15.91	16.34
	(165.35)	(182.30)	(22.26)	(24.42)
NCCPI	0.72	0.72	0.25	0.25
	(0.05)	(0.05)	(0.04)	(0.04)
Observations	524	786	210	315

Note: Corn Planted is the percent of agricultural land that produced corn in a county. Top corn production is the treatment group that includes counties in the top quartile of the NCCPI distribution. No corn production is the comparison group that includes counties in the bottom 10th percentile of the NCCPI distribution.

Figure A.1: Counties in Treatment and Comparison Groups



Note: This map plots counties in treatment and comparison groups. Counties in treatment group are counties with high corn suitability or high productivity land. Counties in comparison group are counties with low corn suitability or low productivity land.