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Article

The economic impact of biofuel policy on the agricultural sector in the Great Plains region, 1997–2017

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Abstract

Global biofuel production has increased over tenfold since 2000 and numerous biofuel production plants have been built in the Great Plains region. We estimate the impact of biofuel plants on the agricultural economy with county-level data on the number of farm operators, net farm income (NFI), and agricultural land values during 1997–2017 for 798 counties in twelve Great Plains states. We find that biofuel production facilities have a small negative association with the number of farm operators, but positive associations with NFI and farmland values in the county where the biofuel plant is located and neighboring (adjacent) counties. Sustained positive associations of biofuel production with farm income and land values are likely to depend on the continuation of national and state government programs of ethanol blend mandates and tax credits. Diminished government bioenergy support could lead to declining farm income and land values in areas near plants.

Keywords: Biofuel policy, Ethanol policy, Biodiesel policy, Agricultural employment, Net farm income (NFI), Agricultural land values

JEL code: Q16

1. Introduction

The biofuel industry is highly subsidized at the federal, state, and local levels (Swenson and Eathington, 2006: 4; De La Torre Ugarte et al. 2007). At the federal level, the Energy Policy Act of 2005 mandated that biofuels be blended with gasoline under the Renewable Fuels Standard Program (7.5 billion gallons by 2012), creating a large subsidy to the ethanol industry. The ethanol blend target was expanded in 2007 by the Energy Independence and Security Act (36 billion gallons by 2022). Many politicians and producer groups have promoted the production and use of biofuels due to perceptions that biofuels will: (1) provide energy security and (2) reduce greenhouse gas emissions. Supported by federal policies, fuel ethanol production in the United States has grown from 1.6 billion gallons in 2000 to 15 billion gallons in 2021 (RFA 2022b; USEIA 2022). Although biofuel can be produced from almost any plant material, the two major types of biofuels are (1) bioethanol (also called ethanol), typically produced from feedstock of corn or sorghum, and (2) biodiesel, most often made from soybeans.

As a result of these subsidies, biofuel production capacity in the USA has grown rapidly from 1.8 billion gallons per year in 1999 to 17.7 billion gallons per year in 2021 (USEIA 2022). A large proportion of the biofuel production in the USA occurs in the Great Plains region (Motamed et al., 2016). Following Hornbeck (2012), the Great Plains region used in this analysis includes 798 counties that share common vegetation and growing conditions in parts of 12 states: Montana, Wyoming, Colorado, New Mexico, Texas, Oklahoma, Kansas, Nebraska, South Dakota, North Dakota, Iowa, and Minnesota. In 2022, these twelve states accounted for 64 per cent of installed biofuel plant capacity, whereas 30 per cent of installed biofuel capacity occurs in the Midwest States Illinois, Indiana, Ohio, Wisconsin, Michigan, and Missouri, (RFA 2022b).

The Renewable Fuels Association (RFA) estimates that in 2021, ethanol was responsible for over 73,000 jobs in the USA (RFA 2022a). Employment is in biofuel manufacturing, distribution, and sales. Ethanol comprises approximately 90 per cent of total US biofuel production. The USA is the largest producer of ethanol, producing 15 billion gallons in 2021, approximately 55 per cent of total global production of ethanol (RFA 2022a, 2022b). Corn is the most used feedstock of ethanol in the USA, and numerous studies have documented an increase in corn production due to expansion of the ethanol industry (Olson et al. 2007; Feng and Babcock 2010; Wallander et al. 2011; Miao 2013; Brown et al. 2014; Fatal and Thurman 2015; Lark et al. 2015; Motamed et al. 2016). Other studies have measured the environmental impacts of the increase in corn production, calling into question whether land use change and farming practices act counterproductive to stated goals of bioenergy policies (Donner and Kucharik 2008; NRC 2012; Lark et al. 2015; Ifft et al. 2018; Sampson et al. 2021; Lark et al. 2022).

In the USA, the number of ethanol plants grew from 50 in 1999 to 201 in 2020, with plant locations concentrated in the Great Plains (over 11,000 mGy in 2022) and Midwest (over 5,000 mGy in 2022, RFA 2022b; USEIA 2022). Proximity to an ethanol plant is likely to lead to higher farm profitability and thus higher farmland values due to an increase in local demand for feedstock and decreased transportation costs to terminal markets (Nickerson et al. 2012; Kropp and Peckham 2015; Zhang and Irwin 2017; Gardner and Sampson 2022).

The objective of this descriptive study is to empirically test if the existence of a biofuel plant in each county is associated with farm income, land values, and the number of farm operators using a sample of 798 Great Plains counties during the time period 1997–2017. Barkley et al. (2023a) showed that changes in farm operator numbers, farm earnings, and agricultural asset values enhance understanding of the dynamics of local economies in response to changes in economic variables such as commodity prices that might be associated with biofuel market expansion. The empirical approach employed here combines information on the construction and capacity expansion of biofuel plants with variation in the levels of farm operator numbers, net farm income (NFI), and agricultural land values across 798 Great Plains counties to measure if the existence of a biofuel plant was associated with the local economy in the county where the plant is located and adjacent counties.

The research reported here advances the literature in three important ways. First, our research estimates the impact of biofuel plants in the Great Plains on three measures of the local agricultural economy: (1) the number of farms,[1] (2) NFI, and (3) agricultural land values. Second, the study estimates the associations of biofuel plants in the county where the plant is located and in adjacent counties, providing a relatively complete measure of the impact of a biofuel plant on regional economic activity. Third, our data covers 12 states across the Great Plains and thus extends a body of literature that has sometimes focused on data having limited geographic scope in the Corn Belt region. Following Wang et al. (2020), this research estimates the impact of two distinct but related measures: (1) the introduction of new biofuel plants and (2) expansion to existing biofuel production capacity. This allows for estimation and measurement of the potential associations of marginal effects on the intensive margin (increases in biofuel production capacity) and nonmarginal effects on the extensive margin (the construction and operation of a new biofuel plant).

2. Literature review

Several studies have estimated the impact of ethanol plants on corn prices (Gallagher et al. 2003; McNew and Griffith 2005; Fort and Parcell 2006; Swenson and Eathington 2006; Olson et al. 2007; Carter et al. 2012; Conde-Meija et al. 2015; Condon et al. 2015; Wu et al. 2017). The review by Condon et al. (2015) estimates that each billion-gallon increase in ethanol production raises corn prices by 2–3 per cent. Additionally, several studies have examined the impact of ethanol plants on the local economy (Parcell and Westhoff 2006; Swenson and Eathington 2006; Swenson 2007; Turnquist et al. 2008). Many of the studies relating ethanol plant introduction to local economic impacts rely on predictive methods utilizing stylized cost and labor assumptions. Towe and Tra (2012) explain, 'the RFS mandate was originally advertised by its supporters as a new source of income for farmers by creating a new market for corn, the main input for the production of ethanol' (721). Swenson and Eathington (2006) suggest that 'ethanol plant corn demand boosts the prices that are received by farmers for their corn or sorghum in the immediate supply area, which are primarily realized as a reduction in gross transport costs relative to the point of demand' (4).

Related research has examined the impact of ethanol plants on land values near the plant. This literature largely relies on hedonic price models to relate stronger basis and lower transportation costs to farmland values. Using data from the Corn Belt, Kropp and Peckham (2015) found that land in the same county as an ethanol plant had values 200–577 USD/acre greater than land outside of the county. Using land transaction data from Kansas, Gardner and Sampson (2022) estimated that ethanol plant construction within 50 km (∼31 miles) conferred an 8.8 per cent land value premium to irrigated land and 6.3 per cent premium to non-irrigated land. The marginal impact on land values of a 10 million gallon per year increase in ethanol capacity near a plant was 4.8 per cent and 1.8 per cent for irrigated and non-irrigated land, respectively. Using surveyed opinions from agricultural lenders across several Great Plains states, Henderson and Gloy (2009) found that ethanol plants increased farmland values, but at a diminishing rate as distance from the plant increased: a non-irrigated land parcel 50 miles away from an ethanol plant would have a 7.2 per cent lower price (94 USD/acre) than an equivalent parcel adjacent to the plant. For irrigated parcels, the difference was 131 USD/acre (6.6 per cent).

Blomendahl et al. (2011) found no evidence of ethanol plants affecting nearby land values in Wisconsin. Nehring et al. (2007) used farm-level data in the Corn Belt to estimate that a 10 per cent increase in ethanol capacity was associated with a 0.3 per cent increase in quality-adjusted land prices. Using data for Iowa, Illinois, Kansas, Minnesota, Nebraska, and Wisconsin, Towe and Tra (2012) found that farmland within 30 miles of an ethanol plant had prices 9–12 per cent greater than those farther away from the plant. Likewise, Zhang and Irwin (2017) found land value increases of 10 per cent within 30 miles of an ethanol plant using transaction data in Ohio.

Relative to research on the impact of ethanol plants on land values, less work has been done on the impact of ethanol plants on farm operator numbers. The economic impact of a new ethanol plant has been investigated by Gallagher et al. (2007) and Swenson and Eathington (2006) using stylized predictive modeling. Parcell and Westhoff (2006) reported that, 'Great interest is given to the local and regional economic effects from the start-up and operation of an ethanol plant.' Swenson (2007) predicted that a 40-employee ethanol plant would add 155 total jobs to the local economy through the multiplier effect. Fortenbery and Deller (2008) found positive effects of ethanol plants on the local agricultural economy. This previous research did not investigate the potential impact of biofuel plants on the number of agricultural producers located near the new plant.

Other research has focused on the impact of ethanol plants on corn prices. FAPRI (2005) found that a 100 MMgy dry mill ethanol plant was associated with a 0.006 USD/bu increase in corn prices and a 0.02 per cent increase in NFI. Fort and Parcell (2006) estimated that a new ethanol plant would increase corn prices by 0.09 USD/bu for corn sold to the plant and increase regional corn prices by 0.10 USD/bu after the start up. Olson et al. (2007) measured the impact of an additional 100 MMgy ethanol plant on corn prices, with a range from 0.16 USD/bu to 0.40 USD/bu.

Utilizing insights from transportation cost analysis, most studies demonstrate that the economic advantage of an ethanol plant dissipates with distance from the plant. McNew and Griffith (2005) provide evidence that the impact of proximity to an ethanol plant depends on whether producers are 'upstream' or 'downstream' of the plant.[2] Utilizing the model presented by McNew and Griffith (2005), upstream producers who are at a greater distance from the plant may benefit more than closer producers located downstream of the plant. Restated, economic gains from transportation cost reductions depend on where the feedstock producer is located relative to both the new plant and the original terminal market. This finding is relevant to our empirical setting because it establishes the possibility that a county located adjacent to a biofuel plant benefits as much or more than the county that is host to the biofuel plant. Our empirical approach tests for this possibility by estimating regression models for both own-county biofuel capacity and adjacent-county biofuel capacity.

3. Method

Let Y_i be the three outcome variables: (1) farm operator numbers, (2) agricultural earnings as measured by NFI, and (3) agricultural land values. We estimate the following Poisson model using biofuel production capacity (MMgy) in each county:

$$Y_{it} = \exp\left(\beta_1 Bio_{it} + \beta_2 \sum_{j \neq i}^{N} W_{ij} Bio_{jt} + \phi' Z_{it} + \eta_l + \tau_t + \epsilon_{it}\right), \tag{1}$$

where Y_{it} is the three outcome variables, Bio_{it} is a measure of biofuel plant capacity in county i in census year t, Bio_{jt} is a measure of biofuel plant capacity in the counties neighboring county i, W_{ij} is a spatial weight equal to 1 if county j is adjacent to county i and 0 otherwise, Z_{it} is a set of time-variant characteristics (e.g. climate, state-level feedstock prices), η_l is a set of cross-sectional dummy controls at the county-level, τ_t are year dummies, and ϵ_{it} is the error term, which we cluster at the county level.[3] Characteristics affecting agricultural outcomes that are fixed over time such as soil properties are thus captured by the cross-sectional dummies. With county and year dummies included, the effect of biofuel plants in Equation (1) is derived from time series variation within counties that is not common to all counties in a particular year. Poisson regression allows for zero and negative values, making it suitable for models of this type, since NFI has some negative observations.[4] Additionally, we explore the nonmarginal impact of ethanol plant construction in a later section and Poisson regression avoids inconsistency associated with ordinary least squares (OLS) estimates in log-linear models (Cameron and Trivedi 2005; Santos Silva and Tenreyro 2006; Wooldridge 2010).

Biofuel plant impacts could be confounded by feedstock prices and production levels which are driven by macroeconomic conditions. Therefore, models were specified to include the potential impact of biofuel feedstock prices on the local agricultural economy. A simple average of corn and soybean prices for each state in the Great Plains data set were included to capture variation in economic returns across locations and time. Sorghum is also used as biofuel feedstock, however, corn and sorghum prices are highly correlated due to arbitrage across space and time. Therefore, a corn and soybean price average is included in the model due to lack of sorghum price data and the collinearity with corn prices.

As previously mentioned, McNew and Griffith (2005) use a spatial grain pricing model to demonstrate how, in some cases, feedstock producers located further from a biofuel plant could benefit more than producers located near the plant. This counterintuitive result is due to the relationship between the locations of the original terminal point of sale, the new biofuel plant, and the feedstock producer. For producers located between the new biofuel plant and the original point of sale, economic gains are highest near the biofuel plant and diminish with distance from the plant, reflecting transportation costs. In short, feedstock producers located further away from the plant can benefit more than those located near the plant, if the distance to the original point of sale, or terminal market, is large. We include the sum of biofuel capacities in the counties neighboring the focal county to capture these possible network effects.

It is important to point out that biofuel plant location is potentially endogenous, due to the presence of time-varying unobservable factors that influence the plant location decision and the outcome variables (Motamed et al. 2016; Li et al. 2018). Specifically, Motamed et al. (2016) identified variables such as transportation infrastructure, competition, water availability, policy environment, and feedstock supply density as determinants of ethanol plant location. For example, biofuel plants are likely located in counties with access to transportation infrastructure and plentiful corn stock. To the extent that these counties have higher crop yields, then they are also likely to have higher farm income and land values. The results presented here may be overstated due to this threat to our econometric approach. Similarly, biofuel plants are unlikely to be located at random in adjacent counties. To the degree that the 'suitability' of biofuel plant in county i is positively correlated with capacity in adjacent counties, the effect of adjacent county capacity will be biased upward (i.e. 'reflection problem' Manski 1993).

It should therefore be emphasized that this research is descriptive, not strictly causal, and does not address the possibility of endogeneity explicitly beyond the use of county and year dummies. Additionally, this research does not account for the possibility of heterogeneous impacts driven by local market structures. For instance, Wang et al. (2020) and Jung et al. (2022) demonstrate how competitiveness and local market structure affects agricultural outcomes such as land use and farm surplus. Lastly, Miao (2013) and Li et al. (2018) define an 'effective' capacity by defining a buffer area around each ethanol plant, calculating the portion of the buffer area that falls within a county, and allocating total ethanol plant capacity to the county according to the county's portion of the buffer region. In contrast, our approach separately considers own-county capacity, and the sum of own-county and adjacent county capacity.

4. Data

We use the Great Plains region for the investigation of the relationships between biofuel plants and farm operator numbers, asset values, and agricultural earnings, due to the high level of biofuel production and similarity in crops grown and diversity in climate and growing conditions. We use Hornbeck's (2012) definition of the Great Plains, a balanced panel of 798 Plains counties with common vegetation and growing conditions from 1997 to 2017, shown in Fig. 1. The data set used here differs from that of Hornbeck (2012) in three ways. First, Hornbeck (2012) used the 1910 county definitions. Many counties were divided into multiple new counties in the period between 1910 and the initial year of our study, 1997. Second, ten counties were omitted due to data availability and confidentiality requirements of the Ag Census. These changes resulted in a balanced panel of 798 Great Plains counties for the five-year increments for 1997–2017.

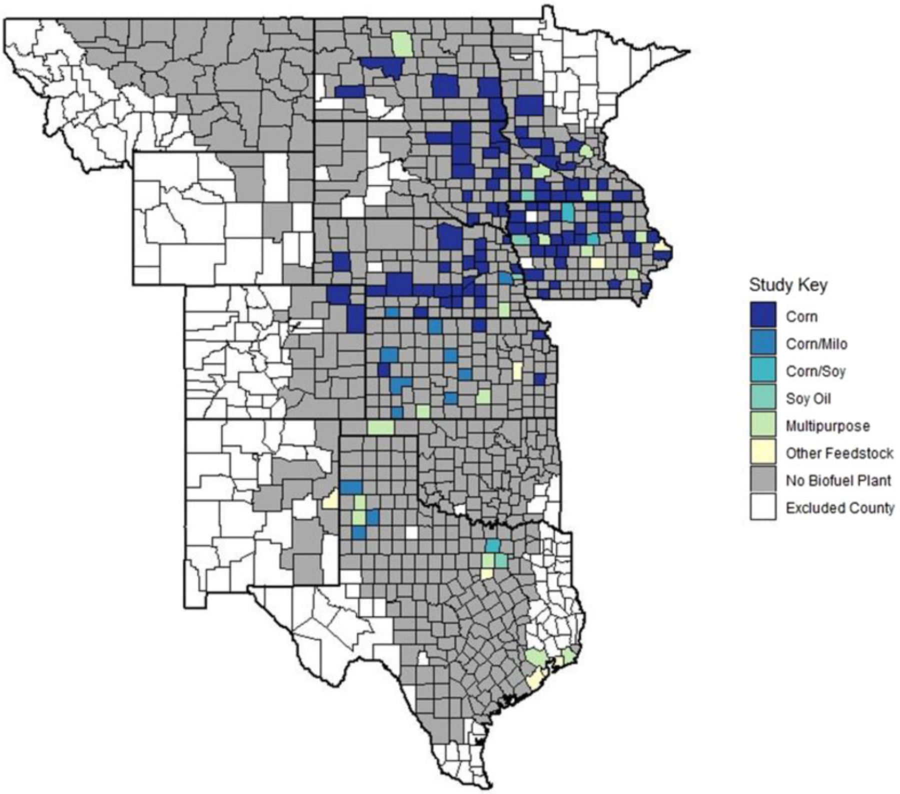

Figure 1. Location of Great Plains biofuel plants
Sources: Biodiesel Magazine; Ethanol Producer Magazine.

The agricultural outcome variables (Y) of NFI, land values, and farm operator numbers are from the US Census of Agriculture (USDA/NASS 2017) and Haines et al. (2018). Census data are available every five years, so the empirical estimates presented here are for five-year increments. Data on annual biofuel production capacity are obtained from Biodiesel Magazine and Ethanol Producer Magazine. Biofuel County Capacity was defined as million gallons per year (MMgy) production capacity of all plants within a county in a given year, as shown in Fig. 2. Adjacent Biofuel Capacity is defined to be the sum of biofuel production capacity (MMgy) in all counties adjacent to the county where the biofuel plant is located. Regional Biofuel Capacity is defined as the sum of within-county Biofuel Capacity and the capacity in adjacent counties (Adjacent Capacity).

Net farm income (US Ag Census, USDA/NASS 2017) reflects income after expenses from production in the current year calculated by subtracting farm expenses from gross farm income, including both cash and noncash income and expenses. NFI observations were deflated using the implicit GDP price deflator, with a baseline year of 2017 (USBEA). NFI includes negative observations, making Poisson regression advantageous.[5] Land values (1000 USD/acre) are estimates of the value of land and buildings (US Ag Census, USDA/NASS 2017). Land values were deflated using the implicit GDP price deflator with a baseline year of 2017 (USBEA). Farm operator number is defined as the number of principal operators whose primary occupation is farming (USDA/NASS 2017). A principal operator is defined as the person primarily responsible for the day-to-day operation of the farm.[6]

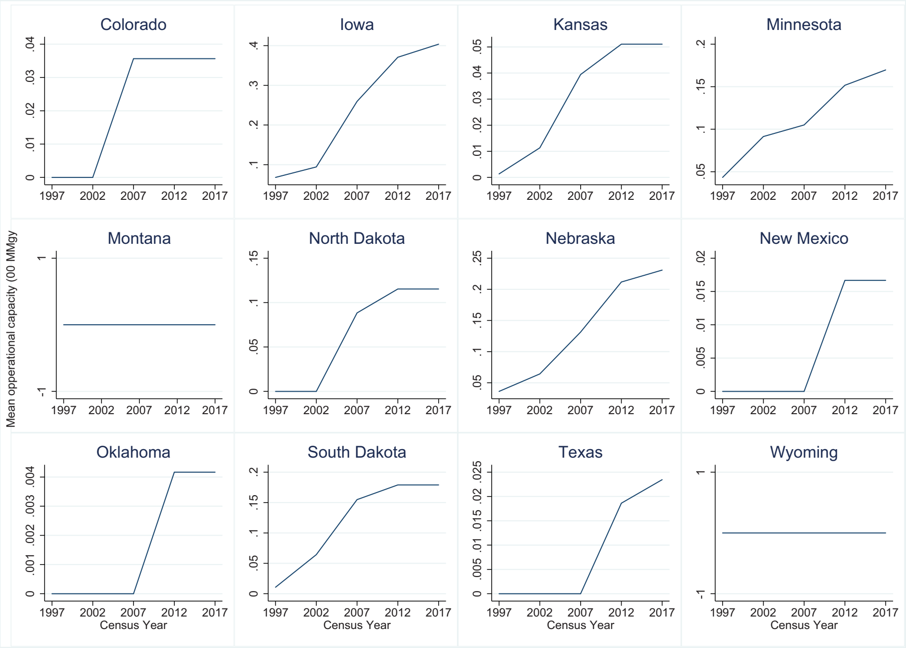

Figure 2. Great Plains States biofuel mean operational capacity, 1997–2017
Sources: Biodiesel Magazine; Ethanol Producer Magazine.

Rural-Urban Continuum Codes (USDA/ERS 2017) are a classification scheme that distinguishes metropolitan counties by the population size of their metro area, and nonmetropolitan counties by degree of urbanization and adjacency to a metro area.[7] Metro and nonmetro categories are subdivided into three metro and six nonmetro categories and each county in the USA is assigned one of the nine codes. In earlier versions of the Rural-Urban Continuum Codes, metro areas with 1 million population or more were subdivided between central counties (Code 0) and fringe counties (Code 1). These two categories were combined, and the new code 1 represents all counties in metro areas of 1 million or more population. To allow for comparability between the old and new codes, we combined code 0 and 1 even for the earlier codes into one (code 1). Definitions of the nine categories appear in Table 1.

Daily gridded weather data are obtained from PRISM and climate variables are constructed for each county using the method described in Schlenker et al. (2006). All climate variables were computed as 30-year rolling averages of yearly weather variables at county level up to the census year so as to capture long-run climate conditions. The climate variables used span the growing season (April–September) following the definitions used by Schlenker and Roberts (2009) and Ortiz-Bobea (2020). The variables include total precipitation, average temperature and degree days. Degree days include season-long extreme (high temperature) degree days (>30 °C) and extreme (low temperature) degree days (<10 °C). A biofuel feedstock price measure at the state level was calculated as the simple average of corn and soybean prices. Corn and soybean prices were taken from the USDA, National Agricultural Statistics Service, *Agricultural Prices* (USDA/NASS). Biofuel feedstock prices were deflated using the implicit GDP price deflator with a baseline year of 2017 (USBEA).

Summary statistics for the three outcome variables (Y_i) and the measures of biofuel plants are shown in Table 1. The mean number of agricultural principal operators in the 798 Great Plains counties was 448 during 1997–2017. For the same period, average reported NFI was 109,464 USD/year, and agricultural land values averaged 1887 USD/acre. Approximately

Table 1. Summary statistics for variables included in biofuel capacity Poisson regressions.

Variable	Mean	Std. dev.	Minimum	Maximum
Farm operators (100)	4.484	2.667	0.210	27.920
Net farm income (USD/year)	47,626	58,829	−55,150	1,041,275
Land value (1000 USD/acre)	1.887	1.852	0.104	26.646
State biofuel price average (USD/bu)	6.232	2.464	2.400	10.860
Biofuel county capacity (100 MMgy)	0.074	0.305	0	5.400
Biofuel county plant (1 = yes; 0 = no)	0.095	0.294	0	1
Adjacent biofuel capacity (100 MMgy)	0.485	1.043	0	8.880
Regional biofuel capacity (100 MMgy)	0.559	1.160	0	8.880
Low temp. (100 GDD/growing season)	19.584	6.011	7.980	45.543
High temp. (100 GDD/growing season)	45.361	40.600	0.882	237.867
Precipitation (inches/year)	20.920	7.015	8.445	62.024
RUC1 metro > 1 million (default)	–	–	–	–
RUC2 metro 250,000–1 million	0.049	0.215	0	1
RUC3 metro <250,000 people	0.074	0.261	0	1
RUC4 nonmetro, adjacent 20,000+	0.029	0.167	0	1
RUC5 nonmetro, nonadjacent >20,000	0.040	0.197	0	1
RUC6 metro adjacent 2,500–19,999	0.173	0.378	0	1
RUC7 nonmet, nonadj., 2,500–19,999	0.218	0.413	0	1
RUC8 rural, metro-adjacent	0.079	0.269	0	1
RUC9 rural	0.276	0.447	0	1

Number of observations = 3,995. Average biofuel plant capacity is approximately 100 MMgy.

9.5 per cent of all included counties in the Great Plains data set had at least one biofuel plant located within the county borders (Biofuel County Plant, Table 1). Biofuel County Capacity averaged 7.4 million gallons per year (MMgy), with a range of zero to 540 MMgy. The variable Adjacent Biofuel Capacity measures biofuel productive capacity in all adjacent counties, with an average of 48.5 MMgy. The variable Regional Biofuel Capacity is the sum of Biofuel County Capacity and Adjacent Biofuel Capacity, measuring the total quantity of biofuel production capacity in a county and all adjacent counties (Table 1).

Summary statistics for the control variables are also reported in Table 1, including climate (three variables) and rural-urban continuum codes (nine variables). These 12 variables capture determinants of the local agricultural economy in each county included in the Great Plains data set. The Metro rural-urban continuum variable (RUC1) is the default category, thus all estimated coefficients for the remaining eight rural-urban categories (RUC2 to RUC9) are interpreted relative to the Metro category (RUC1). Approximately 17 per cent of all included counties are Metro-adjacent (RUC6), about 22 per cent are Nonmetro-adjacent (RUC7), eight per cent are Rural Metro-adjacent (RUC8), and 28 per cent are Rural (RUC9).

5. Results

The main results of the study are reported in Table 2. The regression models include Biofuel County Capacity and Adjacent Biofuel Capacity as the main variables to test the impact of biofuel plants on farm operator numbers (column 1), NFI (column 2), and agricultural land values (column 3). Biofuel production capacity had a small negative but statistically insignificant impact on county farm operator numbers. Each 100 MMgy biofuel plant capacity in adjacent counties is associated with a decrease in the number of principal operators of 1 per cent (the exponent of the estimated coefficient minus one), equivalent to an average loss of 4.5 agricultural producers per county. The magnitude of the own-county and adjacent-county impacts are similar, though the adjacent-county coefficient is estimated with more precision. This provides evidence that the number of farms and farmers in Great Plains

Table 2. Biofuel capacity Poisson regression results.

	(1) Farm operators Est. coef.	(Std. err.)	(2) Net farm income Est. coef.	(Std. err.)	(3) Farm land value Est. coef.	(Std. err.)
Bio. co. cap.	−0.011	(0.008)	0.065***	(0.025)	0.043***	(0.014)
Adj. co. cap.	−0.010***	(0.003)	0.044***	(0.007)	0.039***	(0.006)
Biofuel prices	−0.052***	(0.009)	−0.023	(0.021)	0.103***	(0.037)
Low temp.	−0.008***	(0.003)	0.043***	(0.009)	−0.008**	(0.004)
High temp.	0.015***	(0.001)	−0.023***	(0.002)	−0.011***	(0.002)
Precipitation	0.009***	(0.001)	−0.020***	(0.005)	−0.001	(0.002)
RUC2	−0.027	(0.031)	0.125***	(0.060)	0.024	(0.050)
RUC3	−0.073**	(0.037)	0.098**	(0.053)	0.081*	(0.043)
RUC4	0.019	(0.047)	0.125**	(0.076)	0.034	(0.040)
RUC5	−0.024	(0.045)	0.211***	(0.072)	0.057	(0.045)
RUC6	−0.068**	(0.039)	0.207***	(0.052)	0.052	(0.038)
RUC7	−0.034	(0.034)	0.296***	(0.071)	0.032	(0.041)
RUC8	−0.085***	(0.085)	0.161***	(0.065)	0.083*	(0.047)
RUC9	−0.076**	(0.076)	0.202***	(0.082)	0.026	(0.050)
Pseudo-*R*-squared	0.292		0.842		0.375	
Log-likelihood	−6,538.622		−8,861,623.300		−4,576.969	
Chi square	216,864.520***		40,092.849***		340,658.080***	

Controls include fixed effects for counties, states, and years. Number of observations = 3,995. Robust standard errors clustered by county.

counties is stable, but a small amount of farm consolidation has occurred in counties near biofuel plants relative to counties without adjacent biofuel plants. Specification tests for robustness are included in the Appendix, and show identical qualitative results.

Farm consolidation and labor-saving technological change have decreased the number of farm operators over time (Barkley 1990; Barkley et al. 2023a), but biofuel plants most likely do not change the overall farm financial position enough to result in large and significant changes in the number of principal operators, as discussed below. The control variables other than the biofuel variables explained approximately 29 per cent of the variation in farm operator numbers in the Great Plains, as measured by the Pseudo-*R*-square (Table 2). Farm operator numbers were related to climate, and several of the rural-urban continuum codes at a high level of statistical significance (Table 2, column 1). High temperatures and precipitation were both positively associated with the number of principal operators, while low temperatures were associated with a smaller number of farm operators.

NFI was positively associated with biofuel production capacity in both the county where the biofuel plant is located (Biofuel County Capacity) and adjacent counties (Adjacent Biofuel Capacity). The marginal impact can be quantified: a 100 MMgy increase in Biofuel County Capacity increased NFI approximately 6.7 per cent (the exponent of the estimated coefficient) in the own county, while an equivalent increase in the adjacent counties increased NFI by about 4.5 per cent (Table 2, column 2). These increases in NFI are highly statistically significant, providing some evidence that biofuel plants enhance prices and profitability for producers of biofuel feedstock including corn and sorghum for ethanol and soybeans for biodiesel. On average, this increase amounted to approximately 7334 USD/year in the plant county and 4926 USD/year in adjacent counties.[8] These economic gains are most likely due to savings in transportation costs for agricultural producers located near biofuel plants (McNew and Griffith 2005).

These estimates are likely to be an overestimated, for two reasons: (1) biofuel plants are more likely to be located in counties most suited to biofuel refining due to feedstock production, resulting in self-selection of counties (Motamed et al. 2016), and (2) diminishing returns to biofuel production capacity as more plants are built. Counties having plentiful feedstock production are likely to have greater NFI and are also likely to be viewed as advantageous locations for biofuel plant construction by investors. Our use of county-level dummies will somewhat mitigate this upward bias by controlling for background differences in growing conditions and transportation infrastructure that could drive some of the self-selection. The regression models explain approximately 84 per cent of the variation in NFI. This is larger than the model for agricultural employment (column 1) and agricultural land values (column 3).

The impact of biofuel plants on agricultural land values are shown in Table 2, column 3. The marginal impact of a 100 MMgy increase in biofuel capacity within the county is an increase of approximately 4.4 per cent in agricultural land values. Similarly, a 100 MMgy increase in adjacent counties results in a 4.0 per cent increase in agricultural land values within the county. Thus, expansion in ethanol plant capacity outside of the county has a similar effect on land values as expansions within the counties. This is not entirely surprising given that many empirical studies in the literature demonstrate that the impact of ethanol plants extend out 25–60 miles (Motamed et al. 2016; Li et al. 2018; Sampson et al. 2021), a distance which is greater than the distance from county centers to the edges for many counties in our data set. As expected, commodity prices have a positive and statistically significant impact on land values. The marginal effect of a 1 USD/bu commodity price increase (i.e. 16 per cent increase) is approximately double the magnitude of having an active biofuel plant within the county. The land value model explains 37.5 per cent of the variation in land values, and the biofuel variables are highly statistically significant.

These results are also consistent with the economic theory that asset values represent the discounted net present value of all future earnings: The percentage changes in land values (column 3) are in the same range as the per cent changes in NFI (column 2), providing some evidence that demand increases caused by biofuel plants are capitalized into agricultural land values. We are able to build off previous hedonic measures of biofuel plant proximity by providing estimates of the impact to farmland values and to NFI (the latter being capitalized into the former). For a new biofuel plant of 100 MMgy, agricultural land values increase 83 USD/acre in the plant's own county (i.e. about 4.3 per cent) and 75 USD/acre in counties adjacent to the plant (i.e. about 4.0 per cent). This is lower than the estimates of Kropp and Peckham (2015), who found an increase of 577 USD/acre. This is due to the location of their study in the Corn Belt (Indiana, Illinois, and Iowa), with higher corn yields, land values, and thus greater economic impact of biofuel plants relative to the Great Plains counties included here. Our estimates are slightly conservative when compared against the hedonic price estimates of Henderson and Gloy (2009) who examined data for a portion of the Great Plains.

It is important to emphasize that the results presented here for the Great Plains region are likely to differ from similar study results focused on states in the Midwest region ('Corn Belt'). The Great Plains, on average, have less precipitation and greater levels of irrigation than the Midwestern corn-producing region.

6. Robustness checks

We have estimated several additional model specifications to provide more confidence in the robustness of our main model results presented in Table 2. These additional model results are presented in Table 3 for farm operator numbers, NFI, and agricultural land values, respectively. The major baseline results from Table 2 are presented in column 1 for comparison. An additional specification uses the variable, 'Biofuel Plant' defined to be equal to one for counties with at least one biofuel plant and zero for counties with no plants. The variable, 'Biofuel plant' is included in a regression together with adjacent biofuel capacity (Table 3, column 2), and without adjacent biofuel capacity (Table 3, column 4). The variable, 'Biofuel plant' provides estimates of the nonmarginal impact of a biofuel plant in a

Table 3. Robustness check for biofuel capacity Poisson regressions.

Variable	**(1) Baseline (Table 2)**	(2)	(3)	(4)	(5)
Farm operators					
Biofuel county capacity	−0.011(0.008)	–	−0.017**(0.009)	–	–
Biofuel plant	–	−0.025** (0.010)	–	−0.030***(0.011)	–
Adjacent biofuel capacity	−0.010***(0.003)	−0.010***(0.003)	–	–	–
Regional biofuel capacity	–	–	–	–	−0.010***(0.003)
Net farm income (NFI)					
Biofuel county capacity	0.065***(0.025)	–	0.090***(0.024)	–	–
Biofuel plant	–	0.081***(0.025)	–	0.105***(0.024)	–
Adjacent biofuel capacity	0.044***(0.007)	0.044***(0.007)	–	–	–
Regional biofuel capacity	–	–	–	–	0.047***(0.006)
Agricultural land value					
Biofuel county capacity	0.043***(0.014)	–	0.064***(0.016)	–	–
Biofuel plant	–	0.057***(0.020)	–	0.080***(0.020)	–
Adjacent biofuel capacity	0.039***(0.006)	0.039***(0.006)	–	–	–
Regional biofuel capacity	–	–	–	–	0.039***(0.005)

Regressions include fixed effects for year and county. Robust standard errors clustered by county. Regional capacity is defined as the sum of within-county biofuel capacity and the capacity in adjacent counties, Adjacent capacity.' Number of observations = 3,995.

plant's own county. The adjacent counties capacity included in Table 3, column 2 regressions continue to measure biofuel county capacity, to allow for direct comparison to the baseline regression (Table 3, column 1). Regression models were also estimated for Biofuel County Capacity alone (Table 3, column 3), as well as the sum of own-county biofuel capacity and adjacent county biofuel capacity (Table 3, column 5), defined as 'Regional Biofuel Capacity.' As expected, including own-capacity and adjacent capacity individually in the regression (Table 3, column 1) results in a slight upward bias relative to the sum of own- and adjacent-county biofuel capacity (Table 3, column 5) because biofuel plants spatially cluster. The results could also stem from Manski's (1993) 'reflection problem,' if the county's suitability for ethanol production is positively correlated with ethanol capacity in adjacent counties. All of the specifications reported in Table 3 are similar to the baseline results presented in Table 2.

Regressions were also estimated for NFI using an inverse hyperbolic sine (IHS) transformation (Mullahy and Norton 2022; Bellemare and Wichman 2020). The estimates reported in the Appendix Table A4 are characterized by larger impacts of biofuel capacity and adjacent county biofuel capacity on NFI relative to the Poisson (Table 2) and log-linear (Table A2) estimates. Bellemare and Wichman (2020) suggest that this is typical of the IHS transformation, particularly for outliers or data with observations away from the mean. We have also estimated the regressions using standard errors clustered at the Crop Reporting District level, as reported in the Appendix Table A3. The qualitative interpretation of the coefficients remains unchanged (Table 2).

7. Conclusions and policy implications

This research tested the hypothesis that construction and capacity expansion of a biofuel plant affected the local agricultural economy, as measured by three outcomes: the number of farm operators, NFI, and agricultural land values. Regression results for 798 Great Plains counties during the period 1997–2017 demonstrate that biofuel plants were associated with a small decrease (1 per cent) in the number of principal farm operators. Conversely, biofuel plants had a positive impact on NFI and land values, both in the county where the biofuel plant was located and counties adjacent to the biofuel plant county.

The marginal impact of an additional 100 MMgy of biofuel productive capacity increased NFI by 6.7 per cent (7334 USD/year) in the own county and 4.5 per cent (4926 USD/year) in adjacent counties. If 100 MMgy were added to a county's biofuel capacity, agricultural land values increase 4.4 per cent in the county of the plant, and 4.0 per cent in adjacent counties, providing some evidence that biofuel plant construction is capitalized into agricultural asset values. Restated, if a new 100 MMgy biofuel plant is constructed, it is associated with increased land values of 75 USD/acre in the plant's own county and 83 USD/acre in adjacent counties. These estimates of the capitalization of ethanol plant construction into surrounding farmland values are conservative when compared to previous hedonic estimates in portions of the Great Plains (Henderson and Gloy 2009; Gardner and Sampson 2022).

Expansion in biofuel production has arguably been compelled and supported by national energy policies along with local government incentive programs (e.g. fuel blending tax credits). Recently, the Environmental Protection Agency announced plans to allow the year-round sale of E15 gasoline, which expand ethanol sales.[9] With respect to increases in farm income and land values, the sustained positive impacts of biofuel production are likely to depend on the continued support of national and state government programs in the form of ethanol blend mandates and tax credits. If ethanol blend mandates were rolled back or government support for bioenergy to otherwise slacken, sectors of the agricultural economy that benefitted from bioenergy could become vulnerable to declining farm income and land values.[10] In particular, sectors of the agricultural economy or regions of the Great Plains that have financially leveraged against the wealth gains associated with growth in ethanol markets might be especially vulnerable to slackening bioenergy mandates.

Caution should be taken in the interpretation of these results, as they reflect the economic outcomes of existing biofuel plants and are likely larger than what would occur for construction of new biofuel plants. This is due to market saturation, or self-selection in biofuel plant location, and diminishing returns to biofuel production. Higher biofuel feedstock prices were associated with a small decrease in the number of principal operators, perhaps due to farm consolidation and retirement during times of higher farm returns. Feedstock prices were also found to be positively associated with land values.

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Data availability

The dataset for this research is available at Mendeley Data (Barkley et al. 2023b).

End Note

1 The number of farms is measured by the number of principal operators (USDA/NASS 2017). Beginning with the 2017 Census, farm operators are now defined as 'primary producers,' comparable to the previous definition of 'principal operators.'

McNew and Griffith (2005) define upstream producers as those being in a region where prices are low relative to the ethanol plant. Downstream producers are those located in a high price region relative to the ethanol plant.

3 Regression results with standard errors clustered at the Crop Reporting District are reported in the Appendix.

4 Both Poisson and semi-logarithmic specifications were estimated; the qualitative interpretation of the coefficients remains unchanged.

5 To allow for the semi-logarithmic regression analysis included in the Appendix was conducted as a robustness check, NFI was transformed by adding the largest negative value, equal to minus USD 55,150, plus 0.001 to each observation

6 This measure of farm operator numbers does not include hired farm labor or nonfarm county employment.

7 The Rural Urban Continuum Codes (RUCC) are published by the Economic Research Service of the US Department of Agriculture (USDA/ERS). These codes are updated every ten years, and were published in 1993, 2003, and 2013.

8 These values are found by taking the exponent of the estimated coefficients and evaluated at the sample mean.

9 See: US EPA set to finalize rule on state sales of higher-ethanol gasoline blend—ReganBy Stephanie Kelly. https://www.reuters.com/business/sustainable-business/us-epa-coordinating-with-usda-doe-biofuel-blending-targets-post-2022-regan-2022-09-13/.

10 Exclusive: Biden weighing cuts to 2022 ethanol blending mandate proposalBy Jarrett Renshaw and Stephanie Kelly. https://www.reuters.com/business/energy/exclusive-biden-weighing-cuts-2022-ethanol-blending-mandate-proposal-sources-2022-01-12/.

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Appendix

Table A1. Biofuel capacity Poisson regression results clustered by Crop Reporting District.

	(2) Farm employment		(2) Net farm income		(3) Farm land value	
	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)
Bio. co. cap.	−0.011	(0.010)	0.065***	(0.014)	0.043***	(0.012)
Adj. co. cap.	−0.010***	(0.004)	0.044***	(0.006)	0.039***	(0.008)
Biofuel prices	−0.052***	(0.010)	-0.023	(0.032)	0.103***	(0.037)
Low temp.	−0.008	(0.006)	0.043**	(0.020)	−0.008	(0.006)
High temp.	0.015***	(0.003)	−0.023***	(0.002)	−0.010***	(0.003)
Precipitation	0.009***	(0.003)	−0.020	(0.013)	−0.001	(0.003)
RUC2	−0.027	(0.033)	0.125*	(0.074)	0.024	(0.065)
RUC3	−0.073*	(0.040)	0.098**	(0.047)	0.081*	(0.047)
RUC4	0.019	(0.040)	0.125	(0.082)	0.034	(0.044)
RUC5	−0.024	(0.031)	0.211***	(0.079)	0.057	(0.055)
RUC6	−0.068	(0.046)	0.207***	(0.055)	0.052	(0.051)
RUC7	−0.034	(0.049)	0.296***	(0.084)	0.032	(0.053)
RUC8	−0.085*	(0.048)	0.161***	(0.054)	0.083*	(0.049)
RUC9	−0.076	(0.048)	0.202***	(0.060)	0.026	(0.064)
Pseudo R-square	0.292		0.842		0.375	
Log-likelihood	−6538.622		−8861623.300		−4576.969	

Controls include: fixed effects for counties, states, and years. Number of observations = 3,995.
Robust standard errors clustered by Crop Reporting District.

Table A2. Biofuel capacity log-linear regression results clustered by County.

	(3) Farm employment		(2) Net farm income		(3) Farm land value	
	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)
Bio. co. cap.	−0.007	(0.009)	0.074***	(0.024)	0.031	(0.020)
Adj. co. cap.	−0.010***	(0.004)	0.060***	(0.010)	0.033***	(0.006)
Biofuel prices	−0.055***	(0.011)	−0.042*	(0.024)	0.097***	(0.016)
Low temp.	−0.013***	0.003)	0.017**	(0.008)	−0.016***	(0.003)
High temp.	0.014***	(0.001)	−0.019***	(0.003)	−0.009***	(0.002)
Precipitation	0.010***	(0.002)	−0.008*	(0.004)	0.000	(0.002)
RUC2	−0.064**	(0.033)	0.089*	(0.054)	0.091**	(0.042)
RUC3	−0.086**	(0.037)	0.062	(0.051)	0.131***	(0.043)
RUC4	0.006	(0.053)	0.065*	(0.074)	0.039	(0.040)
RUC5	−0.029	(0.051)	0.093	(0.066)	0.066	(0.048)
RUC6	−0.092**	(0.037)	0.133***	(0.047)	0.102***	(0.034)
RUC7	−0.051	(0.040)	0.161***	(0.059)	0.081**	(0.040)
RUC8	−0.129***	(0.040)	0.141**	(0.055)	0.125***	(0.041)
RUC9	−0.100**	(0.043)	0.170***	(0.064)	0.042	(0.045)
R-square	0.9661		0.6656		0.9674	
Adj. R-square	0.9574		0.5796		0.9590	

Controls include: fixed effects for counties, states, and years. Number of observations = 3,995.
Robust standard errors clustered by county.

Table A3. Biofuel capacity log-linear regression results clustered by Crop Reporting District.

	(1) Farm employment		(2) Net farm income		(3) Farm land value	
	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)	Est. coef.	(Std. err.)
Bio. co. cap.	−0.007	(0.010)	0.074***	(0.015)	0.031*	(0.016)
Adj. co. cap.	−0.010**	(0.004)	0.060***	(0.010)	0.033***	(0.010)
Biofuel prices	−0.055***	(0.010)	−0.042	(0.034)	0.097***	(0.021)
Low temp.	−0.013**	(0.006)	0.017	(0.011)	−0.016**	(0.007)
High temp.	0.014***	(0.002)	−0.019***	(0.003)	−0.009**	(0.004)
Precipitation	0.010***	(0.004)	−0.008	(0.007)	0.000	(0.005)
RUC2	−0.064**	(0.030)	0.089	(0.075)	0.091	(0.064)
RUC3	−0.086**	(0.037)	0.062	(0.057)	0.131***	(0.039)
RUC4	0.006***	(0.049)	0.065	(0.089)	0.039	(0.042)
RUC5	−0.029	(0.048)	0.093	(0.086)	0.066	(0.053)
RUC6	−0.092**	(0.041)	0.133**	(0.059)	0.102**	(0.041)
RUC7	−0.051	(0.040)	0.161**	(0.071)	0.081	(0.051)
RUC8	−0.129**	(0.051)	0.141**	(0.059)	0.125***	(0.042)
RUC9	−0.100*	(0.053)	0.170**	(0.074)	0.042	(0.060)
R-square	0.9661		0.6656		0.9674	
Adj. *R*-square	0.9574		0.5796		0.9590	

Controls include: fixed effects for counties, states, and years. Number of observations = 3,995.
Robust standard errors clustered by Crop Reporting District.

Table A4. Biofuel capacity Inverse hyperbolic sine regression results: net farm income.

	Est. Coef.	(Std. Err.)
Bio. co. cap.	0.220*	(0.122)
Adj. co. cap.	0.236***	(0.060)
Biofuel prices	0.158	(0.246)
Low temp.	−0.177*	(0.095)
High temp.	−0.096***	(0.037)
Precipitation	−0.155***	(0.053)
RUC2	−0.781	(1.312)
RUC3	−1.748	(1.317)
RUC4	−2.049	(1.781)
RUC5	−2.571*	(1.527)
RUC6	−1.414	(1.222)
RUC7	−1.610	(1.300)
RUC8	−1.314	(1.313)
RUC9	−1.645	(1.351)
R-Square	0.6677	
Adj. *R*-Square	0.5824	

Controls include: fixed effects for counties, states, and years. Number of observations = 3,995.
Robust standard errors clustered by county.
