Impact of Ethanol Plants on Local Land Use Change

Ruiqing Miao

We investigate effects of corn-based ethanol plants on local land uses using county-level panel data for Iowa for 1997 through 2009 and an Arellano-Bond difference-generalized method-of-moments estimator. Our results show that ethanol plants have statistically significant effects on the proportion of acres planted to corn in the plants' host counties. Furthermore, *ceteris paribus*, the land-use-change effect of locally owned plants (owned by local farmers or cooperatives) is about twice as large as the effect of plants with nonlocal owners. Environmental implications of the land-use change effect also are explored.

Key Words: Arellano-Bond difference generalized method of moments estimator, ethanol plants, Iowa, land use change, water quality

The first decade of the twenty-first century witnessed a worldwide surge in ethanol fuel production. World ethanol production increased from 4.5 billion gallons in 2000 to 21.9 billion gallons in 2010 (Brown 2011). The United States, due to its abundance of corn, is the leading producer and possesses about one-half of the world's ethanol production capacity. As of January 2012, there were 209 ethanol plants online in the United States (Renewable Fuels Association (RFA) 2012) and the average production capacity of the plants was 71 million gallons per plant per year. Assuming that a bushel of corn produces 2.8 gallons of ethanol, a typical ethanol plant would annually consume 25.4 million bushels of corn.[1] If one further assumes that the yield for corn is 170 bushels per acre, then a typical ethanol plant would require a feedstock supplied by about 149,412 acres of crop land annually. The question naturally arises, then, whether development of ethanol plants has a direct effect on local land use and, if so, the extent of that effect. Intuitively, *ceteris paribus*, farm land located near an ethanol plant is more likely than distant fields to be devoted to corn because it is closest to the terminal market (the ethanol plant). We test this hypothesis and estimate the magnitude of any effects observed.

The answers to these questions have important environmental implications since changes in land use induce changes in greenhouse gas (GHG) emissions and in agricultural chemical applications, which would likely cause new environmental problems (Li and Feng 2008, Donner and Kucharik 2008). By precisely specifying whether such land use changes occur in response to

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[1] In 2009, the United States produced 10.6 billion gallons of ethanol using 3.8 billion bushels of corn (RFA 2010). The average conversion rate is 2.79 gallons per bushel.

Ruiqing Miao is a postdoctoral research associate at the Energy Biosciences Institute of the University of Illinois at Urbana-Champaign. Correspondence: *Ruiqing Miao ▪ Institute for Genomic Biology ▪ 1206 West Gregory ▪ Urbana, IL 61801 ▪ Phone 515.520.1979 ▪ Email miaorong@illinois.edu*.

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establishment of ethanol plants and the extent to which they occur, one can then precisely measure the environmental consequences (e.g., GHG emissions and changes in agricultural chemical applications) of expansion of the ethanol industry. These consequences are of interest to policymakers because if areas surrounding ethanol plants experience a greater magnitude of change in land use, then policies will be needed to improve agricultural management of such areas to mitigate the environmental effects of these land use changes.

There still is no consensus regarding the effect of ethanol plants on local grain prices and land values. McNew and Griffith (2005) showed that ethanol plants increased local grain prices, but studies conducted by O'Brien (2009) and Katchova (2009) did not support that conclusion. Gallagher, Wisner, and Brubacker (2005) showed that grain prices increased in the vicinity of conventional nonlocal-owner plants while locally owned ethanol plants (owned by local corn producers and farmer cooperatives) did not have a statistically significant effect on local grain prices. Lewis (2010) showed that ethanol plants in Michigan and Kansas increased local grain prices while ethanol plants in Iowa and Indiana did not. Regarding the effect of ethanol plants on the value of crop land, Henderson and Gloy (2009), using survey data from agricultural bankers in the Kansas City Federal Reserve District, found that proximity to ethanol plants increased the value of crop land. However, based on county-level cash rental rates for crop land in Iowa for 1987 through 2005, Du, Hennessy, and Edwards (2007) found that ethanol plants did not have a statistically significant effect on cash rental rates.

By answering such questions about the effects of ethanol plants on land use, we contribute to efforts to address the controversies mentioned by adding a supply-side dimension. This dimension can deepen our understanding of the relationship between ethanol plants and local grain prices as well as the relationship between ethanol plants and agricultural land values. Take Katchova (2009), for example. That study showed that establishment of an ethanol plant did not affect local corn prices. Perhaps the plants in question did not affect the local supply of or demand for corn. Or the ethanol plants may have affected both demand and supply of corn but the two effects offset each other. An examination of changes in local land use can identify specific relationships between ethanol plants and local grain prices and hence provide information on effects on local land values.

There is a substantial literature on land use change (e.g., Wu and Segerson 1995, Miller and Plantinga 1999, Lubowski, Plantinga, and Stavins 2008). Land use changes as a result of ethanol production have been attracting increasing attention since Searchinger et al. (2008) and Fargione et al. (2008) published works on the topic in *Science*. Li and Feng (2008) studied the effect of surging ethanol production on changes in land use due to increasing demand for corn. Keeney and Hertel (2009) applied a computable general equilibrium model to simulate global changes in land use from biofuel production. Feng and Babcock (2010) developed a simple and elegant theoretical framework that incorporated market equilibrium responses to biofuel production. They analyzed patterns of change in land use in response to an increase in ethanol demand from market and policy developments. Many studies have examined the local impacts of ethanol plants on grain prices and land values (e.g., McNew and Griffith 2005, O'Brien 2009, Katchova 2009, Gallagher, Wisner, and Brubacker 2005, Lewis 2010, Henderson and Gloy 2009, Du, Hennessy, and Edwards 2007) but few have studied impacts on local land use. We aim to fill this gap. The study closest to this one in terms of scope is Turnquist, Fortenbery, and Foltz (2008); the authors studied the effect of ethanol plants on changes in both the aggregate number of acres in Wisconsin devoted to agriculture and on residential land values in the state. Their results showed that ethanol plants had no effect on changes in agricultural acreage or on residential land values in Wisconsin between 2000 and 2006.

Rather than focusing on aggregate changes in agricultural acreage and residential land values, this study focuses on the effect of ethanol plants on the proportion of agricultural acres devoted to corn, defined as harvested acres of corn for grain over total harvested acres of crops. The analysis is concentrated on Iowa because it is on the frontier of ethanol production in the United States and has experienced significant expansion of its ethanol industry (see Figures 1 and 2).[2] In 2009, Iowa hosted 41 ethanol plants with a total nameplate production capacity of 2.9 billion gallons that accounted for about 27 percent of total production in the United States that year (RFA 2009). Using a panel data set that covers those 41 ethanol plants for 1997 through 2009, we study the effect of ethanol plants on the share of acres planted to corn while controlling for input and output prices.

Of the 41 plants, 11 were under local ownership (i.e., owned by local corn producers or farmer cooperatives). We find that the share of acres planted to corn in a county hosting a local-owner (nonlocal-owner) 100-million-gallon ethanol plant is 7 (4) percentage points higher than a county that does not host such a plant, *ceteris paribus*. We assume that the area that supplies corn for the ethanol plant lies entirely within the county.[3] Based on estimates and parameters obtained from the literature regarding the environmental impacts of land use change, we further quantify the environmental impacts of the land use change (specifically, from corn-soybean (CS) rotation to corn-corn (CC) rotation) caused by the establishment of a 100-million-gallon ethanol plant. We find that establishment of such a plant will cause a 17 percent increase in GHG emissions solely from the change in land use in the host county. Water pollutants from agricultural production, such as nitrate-nitrogen and phosphorus, are affected by between –5.6 percent and 33 percent in the host county.

We next present a theoretical framework in which farmers allocate land between two crops to maximize their profits. Thereafter, we discuss the econometric model and data used in the analysis, the results of our estimates and their implications, and the environmental impacts of the land use changes that come from installation of ethanol plants. In the final section, we offer concluding thoughts and discuss potential extensions of this study.

Theoretical Framework

Following Wu and Segerson (1995) and Miller and Plantinga (1999), we construct a simple land allocation model under a static profit-maximization

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[2] We do not observe a clear trend for total harvested acres of corn in Iowa. A simple ordinary least square regression of total harvested acreage on year shows that the coefficient of year is statistically insignificant (with a t-value at 0.36). This is intuitive because there is little marginal land left in Iowa. As a result, the only major way to increase corn production there is to change from a corn-soybean rotation to a corn-corn rotation. Therefore, we focus on the effect of ethanol plants on the share of corn acreage rather than on corn acreage or total crop land acreage.

[3] It is possible that the corn supply area of a plant is shared by neighboring counties. Here, we make this assumption for ease of explanation.

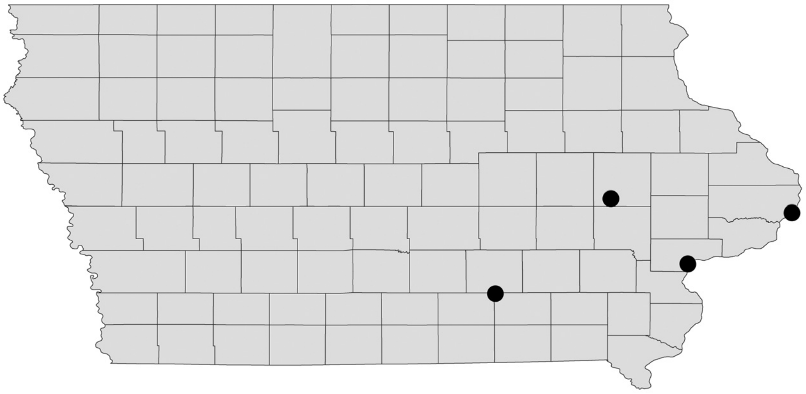

Figure 1. Ethanol Plants in Iowa in 1997

Note: Each dot stands for one ethanol plant.

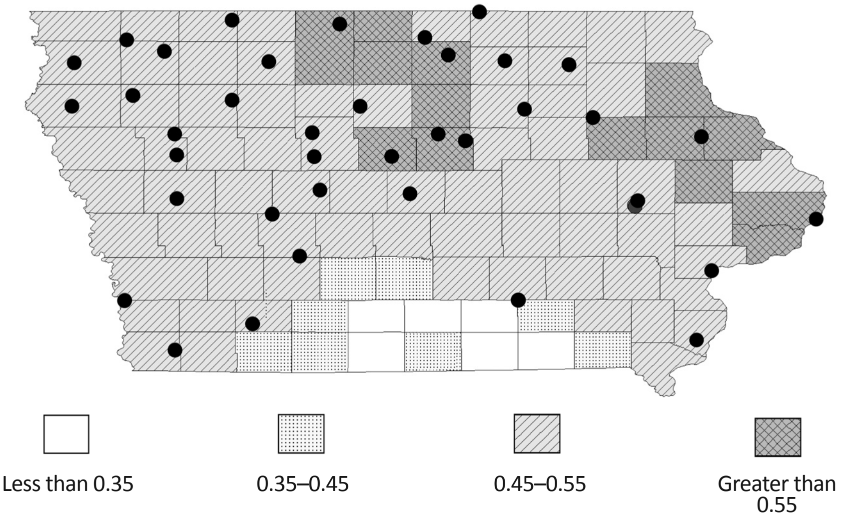

Figure 2. Ethanol Plants in 2009 and County-level Average Corn Acreage Shares for 1997 through 2009 in Iowa

Note: Each dot stands for one ethanol plant. The shading and numbers in the legend represent shares.

framework. Our model diverges from preceding studies in that we include transportation costs to reflect the impact of ethanol plants on land allocation. Establishment of an ethanol plant would provide a new local source of demand for corn and hence could reduce the transport distance between fields and markets. See McNew and Griffith (2005) for a detailed discussion of how ethanol plants reduce corn producers' shipping costs.

Suppose that there are N parcels of land having heterogeneous fertility within a county. Let a_i denote the size of parcel $i \in \{1,\ldots, N\}$. Let $a_{i,j}$ denote the acreage devoted to crop $j \in \{c,o\}$ within parcel i where c stands for corn and o stands for other crops.[4] For each parcel i, the owner determines allocation of land to corn and other crops to maximize total profit. Specifically, then,

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[4] Other crops grown in Iowa include soybeans, hay, corn for silage, oats, and wheat. For 1997

$$\begin{aligned} &\max_{a_{i,j}} \sum_{j\in\{c,o\}} \pi_{i,j}(p_j, \mathbf{w}, a_{i,j}, d_{i,j}, \tau) \\ &s.t. \sum_{j\in\{c,o\}} a_{i,j} = a_i \text{ and } a_{i,j} \geq 0 \end{aligned} \tag{1}$$

where $\pi_{i,j}(\cdot)$ is the profit function of crop j on parcel i, p_j is the price for crop j, $\mathbf{w}$ is a vector of input prices for crop production, $d_{i,j}$ is the distance between parcel i and the closest source of demand for crop j, and τ is the transportation cost rate.

Let $a_{ij}^{*}(p, w, d_i, \tau)$ denote the optimal number of acres allocated to crop j on parcel i, which is obtained by solving problem (1) where $p \equiv (p_c, p_o)$ and $d_i \equiv (d_{i,c}, d_{i,o})$. Then, at a county level, the total number of acres devoted to crop j is

$$\sum_{i=1}^{N} a_{i,j}^{*}(p, \mathbf{w}, d_i, \tau).$$

If we label the share of acres in the county planted to crop j as s_j, then

$$s_j = \sum_{i=1}^{N} a_{i,j}^{*}(p, \mathbf{w}, d_i, \tau) \Big/ \sum_{i=1}^{N} a_i. \tag{2}$$

Equation (2) indicates that the share of acres of a crop is determined by output prices, input prices, distances to markets, and transportation costs. Since establishment of an ethanol plant could reduce the distance corn must be transported but would not affect the transportation distance for other crops, corn production could become more profitable in the area close to the plant. In the empirical analysis, we use the capacity of ethanol plants in a county as a proxy for the magnitude by which an ethanol plant could contribute to reducing the transportation cost. As total ethanol production in a county expands, producers in the county can ship their corn to local ethanol plants. The greater a county's ethanol producing capacity, the greater the reduction in transportation costs for producers.

Econometric Methodology and Data

Adhering to the land use literature, we assume that the crop share in equation (2) has the logistic form. That is,

$$s_{k,j,t} = \frac{\exp(\mathbf{X}_{k,t}\boldsymbol{\beta}_j)}{\sum_{j\in\{c,o\}} \exp(\mathbf{X}_{k,t}\boldsymbol{\beta}_j)} \tag{3}$$

where $k \in \{1,\ldots, K\}$ is an index for the county, $t \in \{1,\ldots, T\}$ is an index for the year, $\exp(\cdot)$ is the exponential function, $\mathbf{X}_{k,t}$ is a vector of regressors, and $\boldsymbol{\beta}_j$ is a vector of parameters for crop j. In this study, $K = 99$ and $T = 13$ since our data set covers Iowa's 99 counties for 13 years, 1997 through 2009. The model can be identified if we normalize $\boldsymbol{\beta}_o$ (the vector of parameters for other crops) in

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through 2009, the average share of harvested acres was 42 percent for soybeans, 6 percent for corn, 1 percent for silage corn, 0.6 percent for oats, and 0.1 percent for wheat (calculated using data from the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture. For simplicity, we combined these five crops into an "other crops" category.

equation (3) as zero. We then obtain the share of acres of corn in county *k* in year *t* as

$$s_{k,c,t} = \frac{\exp(\mathbf{X}_{k,t}\boldsymbol{\beta}_c)}{\exp(\mathbf{X}_{k,t}\boldsymbol{\beta}_c)+1}. \tag{4}$$

After we complete some algebraic rearrangements and add an error term that includes all other factors that affect the share of acres of corn,

$$ls_{k,c,t} \equiv \ln\left(\frac{s_{k,c,t}}{1-s_{k,c,t}}\right) = \mathbf{X}_{k,t}\boldsymbol{\beta}_c + \epsilon_{k,c,t}. \tag{5}$$

In this study, the key independent variables in $\mathbf{X}_{k,t}$ are ethanol plant indices—measures of ethanol production in a county that are labeled $pil_{k,t}$ and $pinl_{k,t}$ (explained hereafter). Other independent variables include three one-year lagged price ratios: (i) the ratio of the soybean price to the corn price, denoted as r^{sc}; (ii) the ratio of the input price index to the corn price, denoted as r^{ic}; and (iii) the ratio of the gasoline price to the corn price, denoted as r^{gc}. We use price ratios instead of absolute price values because share equations are homogeneous of degree zero in prices. Therefore, what matters to the share of acres is the price ratio instead of the price level.[5] We implicitly assume that the expected price in year t equals the realized price in year $t-1$. Since a change in the share of crops in a county is unlikely to affect prices at a national level, national-level price ratios avoid causality running from the dependent variable (the log of the share of acres in corn) to the three independent variables (the price ratios). In addition, the three lagged price-ratio variables do not have a county subscript. To capture the crop rotation effect previously discussed and unobservable factors that lead to slow transitions in land use, we include lags of the dependent variable ($ls_{k,c,t-l}$, $l = 1, \ldots, L$) as explanatory variables where $L \le T-1$ is the maximum lag of the dependent variable. Year t is included as a regressor to capture the impacts of technology advances on land use. This time variable also aides in resolving the spurious correlation problem associated with both ethanol capacity and the share of acres to corn trending upward. Table 1 presents definitions and a statistical summary of the variables. Thus, equation (5) can be written as

$$\begin{aligned} ls_{k,c,t} = {} & \left(\sum_{l=1}^{L}\gamma_l ls_{k,c,t-j}\right) + \beta_{c1}pil_{k,t} + \beta_{c2}pinl_{k,t} + \beta_{c3}r_{t-1}^{sc} + \beta_{c4}r_{t-1}^{ic} + \beta_{c5}r_{t-1}^{gc} \\ & + \beta_{c6}t + u_k + e_{k,t} \end{aligned} \tag{6}$$

where γ_l, $\beta_{c1}, \ldots, \beta_{c6}$ are parameters to be estimated, u_k is the unobserved fixed effect for county k, and $e_{i,t}$ is the error term.

Several econometric issues must be addressed before model (6) can be estimated. The first is simultaneous causality. We are interested in causality that runs from ethanol plants to corn acreage decisions but causality may also run in the opposite direction. That is, ethanol plants are likely to be located in areas that have a high concentration of corn production. For example, Iowa is the number-one corn-producing state in the nation and hosts the largest

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[5] We are indebted to an anonymous referee for comments that led to using price ratios instead of price levels.

Table 1. Variables: Explanation and Summary Statistics

Variable		Mean	Std. Dev.	Min.	Max.
		Observations: 1,287			
ls	Log of the ratio between corn share and other-crop share	–0.11	0.30	–1.35	0.92
s_c	Corn acreage share in a county	0.50	0.07	0.21	0.71
pil	Plant index of locally owned ethanol plants	2.06	9.58	0.00	75.38
$pinl$	Plant index of nonlocal-owner ethanol plants	8.90	20.01	0.00	229.19
r^{sc}	Ratio: soybean price over corn price	2.22	0.20	1.86	2.65
r^{ic}	Ratio: input price index over corn price	56.50	12.59	39.99	84.71
r^{gc}	Ratio: gasoline price over corn price	0.41	0.17	0.16	0.72
p_c	Corn price (dollars/bushel)	3.05	1.06	2.20	6.13
p_s	Soybean price (dollars/bushel)	6.69	2.09	4.32	12.37
p_e	Annual average ethanol price (dollars/gallon)	1.62	0.52	0.98	2.58
p_g	Annual average gasoline price (dollars/gallon)	1.28	0.66	0.43	2.57
p_i	Input price index (1982 = 100)	173.00	70.04	95.00	355.00

number of ethanol plants of any state. Most of Iowa's ethanol plants are located in areas in which a large share of the agricultural land is planted to corn (Figure 2). Consequently, the ethanol-plant index variables (*pil* and *pinl*) are endogenous. The second issue is the presence of a lagged dependent variable. Due to crop rotations, corn acreage decisions in year t are affected by corn acreage decisions in year $t-1$, which were affected by decisions in year $t-2$, and so on. Since most corn in Iowa is planted in a corn-soybean rotation, a year with a high share of acres devoted to corn usually indicates that soybeans will have a high share of acres the following year and corn a low share. It is reasonable to include the lagged dependent variable in the right side of equation (6) to capture this rotation effect. However, the presence of the lagged dependent variable and autocorrelated errors may generate inconsistent parameter estimates (Wooldridge 2003, p. 394). The third issue is that the time-constant variable u_k may be correlated with the independent variables. For example, the suitability of agricultural land in a county for corn production largely determines the number of acres planted to corn. The fourth issue is that the data set has a relatively large panel ($N = 99$) and small time range ($T = 13$).

To address the econometric issues, we apply the Arellano-Bond (AB) difference-generalized method-of-moments (GMM) estimator (hereafter referred to as the AB estimator), which was developed by Holtz-Eakin, Newey, and Rosen (1988) and Arellano and Bond (1991). The AB estimator uses first differences to eliminate the time-constant variable, resolving issues with potential correlation between the unobserved time-constant variable and the independent variables. The estimator then uses the level or difference of further lagged dependent variables as instruments of the lagged dependent variables that appear on the right side of the econometric model. It also uses levels of lagged endogenous variables as instruments for corresponding endogenous variables. Additional instrumental variables can be applied for endogenous variables as well so the estimator resolves the issues of simultaneous causality and autocorrelation. Another benefit of using the AB estimator is that it is appropriate for a panel data set that has a short time range and a large number of panels (Roodman 2009).

We employ two sets of additional instrumental variables for endogenous plant-index variables (*pil* and *pinl*). The first is the aggregate ethanol production capacity of Iowa's local-owner plants and nonlocal-owner plants. Aggregate ethanol plant capacity is correlated with county-level ethanol plant capacities but does not depend on a value for an individual county.[6] The second set of variables includes three-year lagged ethanol prices. Since it takes about three years to construct an ethanol plant and bring it online, a plant's capacity in year t is correlated with the price of ethanol in year $t-3$.[7] Moreover, it is reasonable to assume that the ethanol price will affect allocations of crop land only through the presence of ethanol plants once we control for the price of gasoline in the price ratio format. There are several reasons for this. An increase in the ethanol price will increase ethanol production capacity nationwide and hence increase demand for Iowa corn. Since the price for ethanol is determined largely by the price of gasoline, controlling for the gasoline price effectively controls for demand for corn from ethanol plants (or ethanol production) outside of Iowa, which allows us to separate the effects of ethanol plants in Iowa from ethanol plants elsewhere. Moreover, once we control for the price of gasoline, a shock included in the error term that would affect acres planted to corn would not likely affect the price of ethanol, which is determined largely by crude oil prices or gasoline prices (Feng and Babcock 2010). We do not include the ethanol price in the regressors because the substantial collinearity (with a correlation coefficient of 0.95 in our sample) between gasoline prices and ethanol prices makes the coefficients of both variables insignificant.

We use a balanced panel data set that covers the 99 counties in Iowa for 1997 through 2009. The corn acreage share, $s_{k,c,t}$, is calculated by dividing harvested acres of corn for grain by total harvested acres of all crops in county k in year t. Total harvested acres in a county is the sum of harvested acres of corn, soybeans, hay, corn for silage, oats, and wheat. The acreage data were obtained from NASS.[8] We divide the data set by type of ethanol plant: locally owned and nonlocally owned. This differentiation is of interest because we expect that local plant owners will purchase corn only from their own farms and hence will

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[6] A detailed discussion of using aggregate-level variables as instruments is provided by Wooldridge (2002, p. 133). An example of instruments similar to the ones used here is Mileva (2008), which used the ratio of aggregate long-term capital inflow of sampled countries to the sum of the gross domestic products of those countries as an instrument of an individual country's capital inflow.

[7] We tried using a two-year lagged ethanol price as an instrumental variable and found that the difference in estimation results between the two-year and the three-year lagged ethanol price was negligible. We also tried including both sets of instrumental variables (aggregate ethanol plant capacity and lagged ethanol price) in one estimation and found that the estimation results were only slightly affected.

[8] Our data show that, on average, harvested acres of corn for silage are about 1.9 percent of harvested acres of corn for grain.

have larger land use effects (McNew and Griffith 2005). In the study sample, 11 of the 41 plants have local owners. Based on the plants' annual production capacity, we construct two ethanol plant indexes for each county in each year: one for local-owner plants, *pil*, and one for nonlocal-owner plants, *pinl*. No change of ownership from local to nonlocal or vice versa occurs in our sample.

Calculations of the indexes for local-owner ($pil_{k,t}$) and nonlocal-owner ($pinl_{k,t}$) plants are identical. Here we only illustrate how to calculate $pil_{k,t}$. For one of the 11 local-owner ethanol plants ($h \in \{1, \ldots, 11\}$), we calculate the plant's corn supply area (square miles) in year t, $SA_{h,t}$, using

$$SA_{h,t} = \frac{2 \times 10^6 C_{h,t}}{2.8 \times 170 \times 640} \tag{7}$$

where $C_{h,t}$ is the nameplate capacity in million gallons for plant h in year t. If plant h does not exist in year t, then $C_{h,t} = 0$. We observe changes in the nameplate capacity of a plant caused by production expansion. In the denominator of equation (7), 2.8 gallons per bushel is the conversion rate of corn to ethanol, 170 bushels per acre is the assumed yield of corn in Iowa, and 640 is used to convert square miles to acres. In the numerator of equation (7), the number 2 denotes that the share of corn acres in the supply area is assumed to be 50 percent, the sample mean of our data set. The values of the parameters in equation (7) do not matter very much for our purpose for reasons that will be obvious shortly. Next, following the tradition in the literature on ethanol plant effects, we assume that the corn supply area for an ethanol plant is round and centered at the plant. The radius of the supply area is readily calculated. Third, by applying ArcMap software, we measure the part of the supply area that is within county k, $SA_{h,t}^{k}$, such that

$$\sum_{k=1}^{K} SA_{h,t}^{k} = SA_{h,t}.$$

We then take $SA_{h,t}^{k}$ as given and, by applying equation (7), convert $SA_{h,t}^{k}$ back into ethanol production capacity as the amount of the plant's capacity that affects county k, $C_{h,t}^{k}$. That is, $C_{h,t}^{k} = 2.8 \times 170 \times 640 SA_{h,t}^{k} / (2 \times 10^6)$. Since the equation acts only as a convertor between capacity and affected land area, one can see that the parameters in equation (7) do not matter very much. Finally, in year t, the aggregate ethanol capacity of the locally owned ethanol plants that affects county k is

$$pil_{k,t} = \sum_{h=1}^{11} C_{h,t}^{k} \tag{8}$$

where h is summed to 11 for the number of locally owned ethanol plants in our sample.

The major source of ethanol plant information for this study is annual editions of *Ethanol Industry Outlook* (RFA 2002–2012), which is edited by staff of RFA. Since the earliest available edition was 2002, we obtained production starting years for plants built before 2002 by visiting plant websites, searching local news reports, and contacting plant owners through emails and phone calls. Table 2 provides descriptive information about each plant in the study. The corn (soybean) price is calculated by averaging April prices for December (November) corn (soybean) futures. Corn and soybean future prices were

Table 2. Ethanol Plants in Iowa (1997–2009) Included in This Study

Company Name	Location	Locally Owned	Production Year	Initial Nameplate Capacity[a]	Nameplate Capacity in 2009[a]
Absolute Energy LLC	St. Ansgar	Yes	2008	100	110
Amaizing Energy Holding Co., LLC	Denison	Yes	2005	40	55
Archer Daniels Midland Company	Cedar Rapids	No	1981	25	260[b]
Archer Daniels Midland Company	Clinton	No	1982	25[c]	153[b]
Big River Resources, LLC	W. Burlington	Yes	2004	40	100
Big River United Energy	Dyersville	No	2008	110	110
Cargill	Eddyville	No	1986	35	35
Corn, LP	Goldfield	No	2006	50	60
Global Ethanol, LLC	Lakota	No	2002	53	98
Golden Grain Energy, LLC	Mason City	Yes	2004	40	115
Grain Processing Corp.	Muscatine	No	1996[d]	10	20
Green Plains Renewable Energy, Inc.	Shenandoah	No	2007	50	55
Green Plains Renewable Energy, Inc.	Superior	No	2008	55	55
Hawkeye Renewables, LLC	Menlo	No	2008	110	110
Hawkeye Renewables, LLC	Shell Rock	No	2008	110	110
Hawkeye Renewables, LLC	Iowa Falls	No	2004	50	100
Hawkeye Renewables, LLC	Fairbank	No	2006	115	115
Homeland Energy Solutions	New Hampton	No	2009	100	100
Louis Dreyfus Commodities	Grand Junction	No	2009	100	100
Lincolnway Energy, LLC	Nevada	Yes	2006	50	55
Little Sioux Corn Processors, LLC	Marcus	Yes	2003	40	92
Penford Products Co.	Cedar Rapids	No	2008	45	45
Pine Lake Corn Processors, LLC	Steamboat Rock	No	2005	20	31
Platinum Ethanol LLC	Arthur	Yes	2008	110	110
Plymouth Energy Company, LLC	Merrill	Yes	2008	50	50
POET Biorefining	Gowrie	No	2006	69	69
POET Biorefining	Jewell	No	2006	69	69
POET Biorefining	Hanlontown	No	2004	56	56

Continued on the following page

Table 2. (continued)

Company Name	Location	Locally Owned	Production Year	Initial Nameplate Capacity[a]	Nameplate Capacity in 2009[a]
POET Biorefining	Ashton	No	2004	55	55
POET Biorefining	Corning	No	2007	65	65
POET Biorefining	Coon Rapids	No	2002	54	54
POET Biorefining	Emmetsburg	No	2005	55	55
Quad County Corn Processors	Galva	Yes	2002	18	30
Siouxland Energy and Livestock Cooperative	Sioux Center	Yes	2002	14	60
Southwest Iowa Renewable Energy, LLC	Council Bluffs	Yes	2009	110	110
VeraSun Energy Corp.	Fort Dodge	No	2005	110	110
VeraSun Energy Corp.	Albert City	No	2006	110	110
VeraSun Energy Corp.	Charles City	No	2007	110	110
VeraSun Energy Corp.	Hartley	No	2008	110	110
Xethanol BioFuels LLC	Blairstown	No	2005	5	0
Total				—	2,894

[a] The unit of nameplate capacity is million gallons.

[b] Capacity is divided among the plants. The data source is the official Nebraska state government website, *www.neo.ne.gov/statshtml/122_201001.htm*.

[c] Estimated using total ethanol production in Iowa in 1982 minus the capacity of ADM's other plant in Cedar Rapids (25 million gallons).

[d] Estimated according to Grain Processing Corporation's history, available at *www.grainprocessing.com/corporate-info/history.html*.

Note: The major data source is issues of *Ethanol Industry Outlook*, which is edited by staff of RFA. We obtained production-year information from the websites of each company, local news searches, and contacting companies through emails and phone calls.

obtained from the Chicago Board of Trade. The input price was obtained from Table 8 of the U.S. Fertilizer Use and Price data set published by the U.S. Department of Agriculture's (USDA's) Economic Research Service (ERS) (2010). Gasoline and ethanol prices for 1997 through 2009 were obtained from the Nebraska Energy Office (2013). The price data are not county-specific so in period t the corn price (or soybean or input price) is the same for each county.

Empirical Analysis

We conduct the AB estimations of regression (6), shown in columns 1 through 4 in Table 3, using the Stata command "xtabond2." The table also reports the robust standard errors with small-sample correction. Columns 1 and 2 contain AB estimations for regression (6) with a maximum lag level of one ($L = 1$); columns 3 and 4 show the AB estimations with a maximum lag level of two ($L = 2$). The p-values from the Arellano-Bond test (AB test hereafter) for

Table 3. Estimation Results of Model (6): Dependent Variable $ls_{k,t}$

	Arellano-Bond Estimations				County Fixed Effects Estimations			
Independent Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
$ls_{k,t-1}$	–0.229***	–0.250***	–0.285***	–0.299***	–0.926***	–1.133***	–0.895***	–1.076***
	(0.0374)	(0.0365)	(0.0335)	(0.0351)	(0.0785)	(0.098)	(0.0901)	(0.0999)
$ls_{k,t-2}$	—	—	0.216***	0.209***	—	—	0.317*	0.787***
	—	—	(0.0521)	(0.0458)	—	—	(0.186)	(0.256)
$pil_{k,t}$	0.00429***	0.00388***	0.00316**	0.00317**	0.00227***	0.00257***	0.00227***	0.00244***
	(0.0013)	(0.0013)	(0.0012)	(0.0012)	(0.0008)	(0.0009)	(0.000735)	(0.0008)
$pinl_{k,t}$	0.00381***	0.00366***	0.00198*	0.00190*	0.00276***	0.00300***	0.00225***	0.00187***
	(0.0012)	(0.0012)	(0.0012)	(0.0011)	(0.0005)	(0.0006)	(0.000587)	(0.0007)
r^{sc}_{t-1}	–0.0205	–0.0184	–0.0486***	–0.0450***	–0.101***	–0.101***	–0.0655**	–0.0118
	(0.0167)	(0.0151)	(0.013)	(0.0139)	(0.0218)	(0.0238)	(0.0282)	(0.0347)
r^{ic}_{t-1}	0.127***	0.115**	–0.144***	–0.158***	–0.759***	–0.958***	–1.098***	–1.822***
	(0.0458)	(0.0453)	(0.0453)	(0.0431)	(0.102)	(0.123)	(0.198)	(0.3)
r^{gc}_{t-1}	–1.859	–0.239	28.28***	28.35***	90.61***	107.3***	121.2***	184.8***
	(5.011)	(5.058)	(4.955)	(4.811)	(8.994)	(10.73)	(18.13)	(27.31)
Time trend	0.0165***	0.0171***	0.0212***	0.0219***	0.0538***	0.0593***	0.0341***	0.0107
	(0.0034)	(0.0033)	(0.0024)	(0.0028)	(0.0045)	(0.0052)	(0.0132)	(0.0171)
Hansen test of overidentification: *p*-value	0.08	0.07	0.11	0.10	0.00	0.00	0.00	0.00
Test for first-order autocorrelation: *p*-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Test for second-order autocorrelation: *p*-value	0.00	0.00	0.18	0.25	—	—	—	—

Notes: Robust standard errors are reported in parentheses. The standard errors are corrected for small samples. For Arellano-Bond estimations (columns 1 through 4), the test for autocorrelation is an Arellano-Bond test for autocorrelation in first-differenced errors. For fixed effects estimations (columns 5 through 8), the autocorrelation test is a Wooldridge test for autocorrelation in panel data.

first-order and second-order autocorrelation in first-differenced errors are presented in the last two rows of Table 3. The null hypothesis for the AB test is no autocorrelation in first-differenced errors. When the idiosyncratic errors are independently and identically distributed, the first-differenced errors are only first-order serially correlated. Autocorrelation in the first-differenced errors at a second or higher order indicates that the idiosyncratic errors are correlated and that the moment conditions used in the AB estimations are not valid (Roodman 2009). Therefore, we can use only model specifications that have no autocorrelation in the first-differenced errors at a second or higher order. Since regression (6) with $L = 2$ does not have such autocorrelation but regression (6) with $L = 1$ does, we prefer the estimates with $L = 2$. Moreover, when $L = 1$ in the AB estimation, the Hansen test for overidentification rejects the null hypothesis that all of the instrument variables are valid at a 10 percent significance level (see the bottom of Table 3). However, when $L = 2$ in the AB estimation, the Hansen test does not reject the null hypothesis at the 10 percent significance level. For the estimations shown in columns 1 and 3, we use aggregate ethanol plant capacity as an additional instrument; for estimations in columns 2 and 4, we use a three-year lagged ethanol price as an additional instrument.

Columns 5 through 8 in Table 3 show the results of county-level fixed effects estimations of regression (6). We report these results because we are interested in what the county-level fixed effects estimations would be if we did not use AB estimations to correct the econometric problems associated with regression (6). Columns 5 and 6 include a one-year lag of the dependent variable as a regressor while columns 7 and 8 include both one-year and two-year lags of the dependent variable. The regressions reported in columns 5 through 8 used further lags of the dependent variable and of the endogenous variables as instrumental variables. Moreover, the regressions shown in columns 5 and 7 used aggregate ethanol plant capacity as the additional instrument while the models reported in columns 6 and 8 used the three-year lagged ethanol price as an additional instrument.

The results show that the signs of the estimates in columns 5 through 8 are consistent with those in columns 1 through 4. Also, the coefficients of the two key variables, *pil* and *pinl*, in columns 7 and 8 are close to those in columns 3 and 4. However, there is a large difference between AB estimations and fixed effects estimations in the coefficients of the lagged dependent variables and the price ratio variables. The Wooldridge test for serial correlation shows that there is serial correlation of the idiosyncratic errors of the fixed effects regressions, which indicates that the Arellano-Bond estimations shown in columns 3 and 4 are better choices than the fixed effects estimations.

When we compare columns 3 and 4 in Table 3, we find no significant quantitative difference between the parameters. For example, in column 3 the coefficients of two key variables in our study, the local-owner and nonlocal-owner plant indexes, are 0.00316 and 0.00198, respectively. In column 4, the same coefficients are 0.00317 and 0.0019. The variables are significant in both model specifications. Therefore, results from the two specifications regarding the effects of ethanol plants on land use are virtually the same. Since the *p*-value for the regression in column 4 is larger than the *p*-value in column 3 for the AB test in second-order autocorrelation (0.25 versus 0.18) and a larger *p*-value indicates that idiosyncratic errors in the model are more likely to be independent, we focus on the estimation results shown in column 4 in the remainder of the discussion.

Looking at the results in column 4 of Table 3, we observe that the coefficient of the local-owner ethanol-plant index (*pil*), 0.00317, is significantly larger than that of the nonlocal-owner ethanol-plant index (*pinl*), 0.0019. To simplify the discussion going forward, we assume that the share of corn acres in a county is 50 percent, the sample mean of the data set, and that the corn supply area of an ethanol plant falls entirely within that county. In that case, establishment of a 100-million-gallon locally owned ethanol plant in that county would increase the share of acres devoted to corn in the county to 57 percent.[9] However, when the 100-million-gallon ethanol plant is not local-owned, the share of corn acres would increase to 54 percent. Thus, a local-owner ethanol plant has a larger influence on land use than a nonlocal-owner one. This conclusion is intuitive because local owners are more likely to purchase corn from their own farms (McNew and Griffith 2005).

One can calculate the long-term effects using the estimates shown in column 4 of Table 3. By setting $ls_{i,t} = ls_{i,t-1} = ls_{i,t-2}$ and rearranging equation (6), we obtain the long-run effect of locally owned ethanol plants, β_{pil}^{lr}:

$$\beta_{pil}^{lr} = \frac{\beta_{c1}}{1 - \gamma_1 - \gamma_2}. \tag{9}$$

Plugging corresponding coefficients from column 4 into equation (9), we obtain $\beta_{pil}^{lr} = 0.0029$. In the long run, then, a local-owner 100-million-gallon ethanol plant will increase the ratio between share of corn acres and share of other crop acres by 29 percent in the host county. Similarly, we can calculate the long-run effect of nonlocal-owner ethanol plants, $\beta_{pinl}^{lr} = 0.0017$. By the same procedure described in footnote 9, we determine that establishment of a locally owned 100-million-gallon ethanol plant will cause the share of corn acres to increase over the long run to 56.3 percent in the host county. For a nonlocal-owner plant, the share of corn acres increases to 53.9 percent. Thus, an ethanol plant's long-term effect on the share of acres planted to corn is slightly smaller than the short-term effect.

These calculations are consistent with a standard supply-demand analysis for the corn market. Imagine a positive demand shock caused by establishment of an ethanol plant in period *t*. That shock will shift the corn-demand curve upward and increase the price for corn. In period $t + 1$, corn producers respond to higher prices by producing a corresponding quantity of corn. In the long run, when a new equilibrium is reached, the equilibrium price and quantity supplied (i.e., the long-run effects) will be smaller than the first-round reaction of the corn supply.

We thus conclude that establishment of ethanol plants can increase the local supply of corn in both the short run and the long run. This increase in supply will put downward pressure on corn prices and hence on land values. However, the presence of ethanol plants can generate upward pressure on corn prices and land values by increasing demand for corn and reducing the cost of shipping corn to demand centers (McNew and Griffith 2005). The magnitude

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[9] If the share of corn acres is 50 percent, the ratio between the share of corn acres and the share of other crops is 1. The new ratio after the 100-million-gallon ethanol plant comes online will be 1.317 because, according to the coefficient in column 4 of Table 3, the additional 100 million gallons of ethanol production by a locally owned plant will increase the ratio between corn acres and acres of other crops by 31.7 percent. Suppose the new share of corn acres is s'. Then, solving equation $s' / (1 - s') = 1.317$ generates $s' \approx 57$ percent.

of change in the equilibrium corn price or land value after establishment of an ethanol plant depends on the relative magnitudes of these opposing forces. This complex interplay explains why some recent studies of the effects of ethanol plants on grain prices and land values have generated contradictory findings.

From column 4 in Table 3, we see that an increase in the soybean-corn price ratio or the input-corn price ratio decreases the share of acres planted to corn in a county, which is consistent with intuition. However, the coefficient of the gasoline-corn price ratio requires some explanation. On one hand, since gasoline is an input in agricultural production when used as fuel for agricultural machinery, gasoline becoming relatively more expensive would make corn production less profitable. On the other hand, however, the price of gasoline is highly correlated with the price of ethanol (a coefficient of 0.95 in our sample) so an increase in the price of gasoline could make ethanol production more profitable and spur additional planting of corn. Since fuel accounts for only a small part of the cost of corn production, it is reasonable to assume that gasoline's influence on the price of ethanol would dominate its effect on the cost of corn production.[10] Thus, the coefficient of the gasoline-corn price ratio is positive and significant.

Environmental Impacts: A Numerical Example

Ethanol plants can generate indirect environmental impacts by affecting farmers' land use decisions. For example, corn production typically requires a larger quantity of fertilizer than soybean production, leading to additional GHG emissions and fertilizer run-off. We investigate these environmental impacts by comparing GHG emissions and levels of water pollutants under two scenarios: a baseline scenario with no ethanol production and an ethanol-plant scenario in which a 100-million-gallon corn-based ethanol plant is established. These calculations are based on the estimates shown in column 4 of Table 3 and on parameters for the environmental impacts of GHG emissions and water quality obtained from published research (Feng, Rubin, and Babcock 2010, Thomas, Engel, and Chaubey 2009).[11] We do not consider emissions at the refinery phase of ethanol production. In our calculation, we assume that the ethanol plant has a local owner (impacts of nonlocal-owner plants can be calculated in the same way). Since impacts of nonlocally owned ethanol plants on land use are less significant than impacts from locally owned plants, we expect that nonlocal-owner plants will have a smaller environmental impact at the county level. For the baseline scenario, the share of corn acres and the total crop land acres in a county are assumed to be the sample means of the data, 50 percent and 242,871 acres. We further assume that only corn and soybeans are planted in the county and that a CS rotation is the baseline production process.

If a locally owned 100-million-gallon ethanol plant is established in a county, then, as calculated in the previous section, the share of acres devoted to corn will increase to 56.3 percent in the long run. As a result, 12.6 percent of the acres in the county will be converted from a CS rotation to a CC rotation. According to Tables 2 and 3 in Feng, Rubin, and Babcock (2010), we know that

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[10] For example, according to cost information for corn production in Duffy (2013), fuel accounts for no more than 10 percent of the total cost of corn production.

[11] In states in the northern Great Plains such as North and South Dakota, ethanol production's effect on wildlife and wildlife habitats is also of concern. We refer readers to Bookhout (2012) for a detailed study of this issue.

(i) there will be a 10 percent decrease in corn yield when switching from CS rotation to CC rotation and (ii) producing the same quantity of corn from the CC rotation will emit, on average, 35 percent more GHGs than producing from the CS rotation.[12] Therefore, we know that per-acre GHG emissions under the CC rotation will be 21.5 percent higher than emissions under the CS rotation (calculated as (1 – 10%) × (1 + 35%) – 1). From Table 4 of Feng, Rubin, and Babcock (2010), we know that corn production per acre under a CS rotation will generate about 185 percent more GHG emissions than will soybean production. Therefore, we calculate that one acre of corn under the CC rotation generates about 246 percent more GHG emissions than an acre of soybean production: (1 + 185%) × (1 + 21.5%) – 1. Based on this information, we determine that the increase in GHG emissions under the ethanol-plant scenario is approximately 17 percent $(12.6\% \times [0.5 \times (21.5\% + 247\%)] \approx 17\%)$. We multiply the sum of 21.5 percent and 247 percent by 0.5 because half the land is devoted to corn and half to soybeans when no conversion occurs. In terms of absolute quantities, the 17 percent emission increase in the county means that the equivalent of 2,691,982 kilograms (kg) of additional carbon dioxide (CO_2) will be emitted per year.[13] Feng, Rubin, and Babcock (2010) reported an industry average of 3.18 kg of CO_2-equivalent per gallon of ethanol produced in the refinery phase. Thus, on average, a 100-million-gallon ethanol plant will emit 3.18 million kg of CO_2-equivalent per year in the refinery phase if running at full capacity. One can see, then, that the additional GHG emissions caused by land use changes in response to an ethanol plant are about 84.7 percent of the plant's total GHG emissions at the refinery phase.

Next we examine impacts on water quality from a locally owned 100-million-gallon ethanol plant. For this analysis, we obtained environmental impact coefficients from Thomas, Engel, and Chaubey (2009), a study of water-quality impacts of corn production under CS and CC rotations based on three types of soil in Allen County, Indiana.[14] In columns 1 and 2 of Table 4, we present the water-quality-impact parameters. We use parameters related to Hoytville clay soil because its corn yield potential is similar to yields of corn grown in Iowa and it accounts for 90 percent of the area studied in Thomas, Engel, and Chaubey (2009). We incorporate impacts of corn production on erosion, nitrate-nitrogen run-off and leaching, total phosphorus, atrazine run-off and leaching, and pyraclostrobin. For example, when a producer changes from a CS to a CC rotation, annual erosion will rise from 0.24 to 0.29 metric tons per acre, a 22 percent increase. Nitrate-nitrogen leached to the ground will rise from 2.78 to 4.22 kg per acre, a 52 percent increase. The impact of land use changes generated by the 100-million-gallon ethanol plant on water quality equals the annual percentage increase in the environmental impact per acre (e.g., the 22 percent increase in nitrate-nitrogen leaching) times the proportion

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[12] In this case, corn yields decline and GHG emissions increase because the CC rotation foregoes the benefit of carryover nitrogen provided by the soybean crop. As a result, producers typically apply more nitrogen.

[13] We calculate the 2,691,982 kg of additional CO_2-equivalent as follows. First, from Table 4 of Feng, Rubin, and Babcock (2010), we obtain weighted average emissions from soybean and corn production in Iowa under a CS rotation, about 33.9 and 96.5 kg per acre respectively. The weight is the distribution of tillage for corn and soybeans listed in the table. Second, we calculate the increase in emissions as 17 percent × 242,871 × 0.5 × (33.9 + 96.5) ≈ 2,691,982.

[14] Unfortunately, we could not find similar studies of the effects of Iowa corn production on water quality. We believe that the results from Thomas, Engel, and Chaubey (2009) provide reasonable approximations.

Table 4. Water-quality Impacts of Land Use Change Caused by Establishment of a 100-million-gallon Ethanol Plant

Impact	1 CS Rotation	2 CC Rotation	3 Percent Increased	4 Percent Increase Caused by Land Use Change	5 Absolute Quantity Increase in a Typical Iowa County
Erosion (tonnes per acre)	0.24	0.29	22	2.8	1,610
Nitrate-nitrogen in run-off (kilograms per acre)	1.41	1.56	11	1.4	4,706
Nitrate-nitrogen leached (kilograms per acre)	2.78	4.22	52	6.5	44,211
Total phosphorus (kilograms per acre)	0.06	0.23	263	33.1	5,201
Atrazine in run-off (parts per billion)	3.34	4.10	23	2.9	—
Atrazine leached (parts per billion)	0.09	0.05	–44	–5.6	—
Pyraclostrobin with sediments (grams per acre)	0.06	0.11	73	9.2	1,362

Notes: Data in columns 1 and 2 were obtained from Thomas, Engel, and Chaubey (2009). Using this data, we calculated impacts on water quality, which are listed in columns 3 through 5. Specifically, column 3 shows percentage increases from column 1 to column 2. Column 4 is calculated by multiplying the values in column 3 by 12.6 percent; 12.6 percent of crop lands are switched from a CS rotation to a CC rotation in response to establishment of a 100-million-gallon ethanol plant. Column 5 is calculated as 242,871 × 12.6% × (column 2 – column 1) where 242,871 is crop land acreage for a typical Iowa county.

of total acres of land that will be converted to the CC rotation (12.6 percent). Columns 4 and 5 of Table 4 report the results of these calculations. Changes in water-pollution components in the county range from –5.6 percent to 33 percent. Specifically, losses of nitrate-nitrogen increase 1.4 percent and total phosphorus in surface run-off increases 33 percent, which amounts to an annual loss of 4,706 kg of nitrate-nitrogen and 5,201 kg of phosphorus (column 5). The concentration of atrazine (a component of popular herbicides) in run-off increases 2.9 percent. However, the concentration of atrazine leached to ground water decreases 5.6 percent. This may be because surface run-off increases when land is converted to a CC rotation and atrazine is a relatively mobile compound that may be more likely to wind up in run-off than to leach into the ground.

Conclusions and Discussions

We analyzed the effects of land use changes that occurred in Iowa between 1997 and 2009 in response to establishment of ethanol plants by applying a logit land-share model. AB estimation addressed econometric issues associated with the model (autocorrelation, endogeneity, unobserved time-constant variables, and sample size). Using a county-level panel data set consisting of shares of crop acres in Iowa devoted to corn, indexes of production capacity of the ethanol plants, and multiple price ratios, we demonstrated that ethanol plants had a significant effect on land use in a county. In particular, the effect of locally owned plants was nearly two times larger than the effect of nonlocally owned plants. Moreover, by incorporating perspective on the supply dimension, we shed light on the relationship of ethanol plants to local grain prices and land values.

Once the relationship between ethanol plants and local land use was established, we further estimated the direct environmental effects of plant-induced land use changes. The results show that changing the crop rotation from corn-soybean to corn-corn had a significant negative impact on the environment via increased GHG emissions and degraded water quality. A useful expansion of this study would be to enlarge the sample to include all plants in the United States. This would allow for a comprehensive study of the economic and environmental impacts of corn-based ethanol production.

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