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Spatial Competition and Ethanol Plant Location Decisions

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ABSTRACT

Ethanol is one of the fastest growing industries in the United States. This study estimates factors that impact location decisions for new ethanol plants using logistic regression analysis and spatial correlation techniques. The results indicate that location decisions are impacted by county agricultural characteristics, competing ethanol plants, and state-level subsidies. Spatial competition is particularly important. Existence of competing ethanol plants reduces the likelihood of making a positive location decision, and this impact decreases with distance. Finally, state-level subsidies are significant and a very important variable impacting ethanol location decisions. [JEL Classification: C13, C21, C25, C35, Q42]. © 2012 Wiley Periodicals, Inc.

1. INTRODUCTION

One of the most dramatic and important changes in agriculture in the recent decade is the growth of investment in the ethanol industry. Expansion of this industry has been driven in part by federal and state mandates and subsidies, but also by technology and the dynamics of the United States and world energy sectors. Proximity of ethanol plants to grain production and competitors are important components of plant location decisions. Growth of the ethanol industry has led to increased demand for corn, the primary feedstock for U.S. ethanol production, and in response, acreage planted to corn increased 19% (in 2007) to 93.5 million acres, which is the highest level since 1944 (National Agricultural Statistics Service, 2007). Corn produced for ethanol now comprises about 35% of corn acres in the United States. Ethanol provides a new form of value-added agriculture, generates a large number of jobs (allegedly it supports 400,000 jobs), and there has been intense interstate competition, as well as local competition, that influence ethanol plant location decisions. Despite the popularity among some for support of this industry, it has confronted challenges and these are escalating (see Loftus, 2010, for a recent summary).

The purpose of this article is to analyze factors that impact location decisions for ethanol plants. Technically, we determine factors that affect plant location decisions. The results have important public and private implications. The latter relates to understanding the spatial and competitive factors impacting location decisions. Public implications relate to the role and effect of state-level subsidy regimes that seek to impact location decisions. We analyze decisions that have resulted in observations of current plant locations. There are no doubt many proprietary analyses that have been and are being conducted on ethanol plant location decisions, but there are few published studies that analyze location decisions and factors that impact them. We examine the impacts of counties' agricultural characteristics and the spatial dimensions of competition and state subsidies on ethanol plant location decisions, which have resulted in some counties having plants and others not. We build on other recent studies using spatial autocorrelation to analyze spatial competition (Anselin, 2003; Anselin, Bongiovanni, & Lowenberg-DeBoer, 2004; Irwin & Bockstael, 2003; McMillen, 1995; Nelson, 2002; Nelson

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& Geoghegan, 2002; Sarmiento & Wilson, 2007) and more recent specifications (Kelejian & Prucha, 2001; Klier & McMillen, 2008).

Our econometric analysis follows the McMillen (1995) and the Sarmiento and Wilson (2007) model of spatial competition using a discrete spatial autocorrelation model. The model differs from the specification in Klier and McMillen (2008), which uses a linearized two-stage estimator, compared to our concentrated likelihood approach. The analysis addresses how geographical proximity to other plants impact ethanol plant location decisions. Results underscore the importance of agricultural characteristics in explaining locations of ethanol plants. Acreage planted to corn and other crops, as well as nonethanol demand for corn, are primary factors that impact plant location decisions. We also examine the role of subsidy incentives, which vary across states and are an important component of interstate competition for value-added activities, on ethanol plant location decisions.

The existence and location of competing plants is found to reduce the likelihood of ethanol plant location decisions, but this effect is ameliorated by local agricultural characteristics and subsidies. After accounting for the agricultural characteristics of a county, we find that spatial competition among ethanol plants negatively impact plant location decisions. Spatial relationships of corn production also have a significant impact.

2. DEVELOPMENT OF THE U.S. ETHANOL INDUSTRY

An important change in U.S. grain consumption is corn use for ethanol. The ethanol industry has been expanding during the past decade, and its rate of growth is expected to accelerate over the next few years. Ethanol use for automobile fuel dates back to the beginning of the 20th century, but the ethanol industry consumed a minor portion of U.S. corn production until it began its major expansion at the beginning of the 21st century. The rapid increase in ethanol production has been driven to a large extent by government policy. The ethanol industry receives government support through federal and state subsidies, import protections (Loftus, 2010), a renewable fuels standard, and bans on methyl-tertiary-butyl ether (MTBE), though some of this is changing. Federal and state tax incentives make ethanol processing economically attractive in the Midwest, though these effects are somewhat mitigated by the difficulties and the high cost of transporting ethanol. The Energy Policy Act of 2005 included a renewable fuels standard that requires annual U.S. ethanol and biodiesel consumption to increase each year to a total of 7.5 billion gallons by 2012. The banning of MTBE by many states has also created demand for ethanol. Some states are required by federal policy to blend an oxygenate into gasoline to help the fuel burn cleaner and reduce air pollution. MTBE has been the primary oxygenate used, but it is being phased out as it has been found to pollute ground water, and ethanol, also an oxygenate, is increasingly being used as a replacement (Energy Information Administration [EIA], 2006b).

Since this early legislation, more recent legislation has impacted this industry. Specifically, the 2007 Energy Independence and Security Act (RFS2) made a number of changes. It increased volumes of renewable fuel to 36 billion gallons and created a separation of the volume requirements into four separate categories of renewable fuel: cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel. It also changed the definition of renewable fuels, and created restrictions on the types of feedstock's that can be used to make renewable fuel, and the types of land that can be used to grow and harvest feedstocks.

Production of corn-based ethanol in the United States, which currently represents all of the commercially produced ethanol in the country, rose from 1.63 billion gallons in 2000 to 4.86 billion gallons in 2006, a 300% increase (Renewable Fuels Association, 2007) and is currently approaching 13+ billion gallons (ProExporter, 2010). The time span in ethanol plant development (planning, regulatory approval, construction, and start-up) spans a number of years: At any one time, numerous plants are at varying stages of development. There were 115 ethanol plants operating nationwide in April 2007 with a capacity to produce 5.75 billion gallons per year; an additional 86 plants are under construction or expanding, which will increase annual capacity by 6.34 billion gallons to approximately 15 billion gallons per year (Renewable Fuels Association, 2007). ProExporter (2006) has indicated that an additional 369 projects are in the development phase, representing an additional 24.7 billion gallons of ethanol capacity (Mann Global Research, 2006).

Projections from the EIA (2006a; 2010) suggest that ethanol production will increase from 10 billion gallons to nearly 14 billion gallons in 2015. Growth in demand should slow after 2015, increasing to 17.7 billion gallons by 2035, although many policy makers are promoting a more aggressive renewable fuels standard.

There are a number of aspects of growth in the ethanol industry that are important to this study. First is the location of ethanol plants (Renewable Fuels Association, 2006). Though ethanol production was earlier concentrated in the Eastern Corn Belt, recent expansion has been concentrated in the Western Corn Belt, which now has about 42% of the capacity. The Central Plains is the third largest region. Second, as production of ethanol increases, so does production of distillers' dry grains (DDGs), the principal byproduct from ethanol production. Wide-scale use of the byproduct is evolving, and there is much to be learned about its feeding value and shipping characteristics. A small, though growing amount is exported and is influenced by its lower value and higher cost of shipping—an increasing portion is being shipped in containers. The maximum amount that can be used in rations varies by animal type and herd composition. The rate of adoption of DDGs for corn is less than the rate of substitution in corn rations (i.e., a lot more corn could be displaced with wider adoption of DDGs for livestock rations). The substitution rate of DDGs for corn in livestock is 40 lbs. of corn displaced by 400 lbs. of DDGs; and for swine and poultry, 177 lbs. of corn is displaced by 200 lbs. of DDGs (Urbanchuk, 2003). DDGs are mostly fed to cattle; swine and poultry are largely untapped markets (Otto & Gallagher, 2003).

A third issue is the profitability of ethanol plants and the ability of the industry to meet the growing demand. ProExporter (2006) indicated that the ethanol margin dropped from 152 cents/bushel of corn processed in 2005 to 44 cents/bushel in 2006, but this was still attractive enough to justify additional investment. The ethanol margin stabilized in recent years at about these levels. In contrast, Goldman Sachs (Red River Farm Network, 2006) expressed worry about high corn prices, indicating that rising corn prices threaten profitability of ethanol. Margins for ethanol plants declined in 2006 as the corn price increased 55%, and the price of ethanol rose just 8%. Without processor incentives and tax credits, Goldman Sachs believed many biofuel plants would be unprofitable. Indeed, during 2008 margins vacillated at near nil and in some cases were negative. This had the effect of encouraging only marginal expansions and otherwise deferred commercialization of many new projects.

Finally, there has been much discussion about how U.S. agriculture will respond to this change in demand. To support the growing ethanol industry will require yield and productivity increases (Meyer, 2006; Schlicher, 2006; Smith, 2006; Sosland Publishing, 2006) and additional acres shifted to corn, which could come from changes in rotations (Fatka, 2006b; Hart, 2006b), reductions in soybean acres, or a shift of Conservation Reserve Program (CRP) land to corn (Fatka, 2006a; Hart, 2006a; Mann Global Research, 2006). Since this evaluation began, some of the major agbiotechnology companies have initiated plans that would allow a doubling of corn yields by 2030 (e.g., Monsanto) which would quite drastically impact the industry. The ability to shift CRP acres into corn acres, however, is highly spatially dependent (Mann Global Research, 2006; Pates, 2006). The USDA Chief Economist Collins (2006) indicated that ethanol plants will be able to bid corn away from a variety of other uses, and that the United States will need substantial increases in corn acreage to prevent reductions in exports.

3. EMPIRICAL ANALYSIS OF ETHANOL PLANT LOCATION

3.1. Strategic Interaction and Location Decisions

The motivation for the specification below is based on geographic competition among competing firms in making ethanol plant location decisions. The specification is essentially a reduced form expression of ethanol plant locations. The hypothesis is that spatial competition, among other factors, impacts location decisions. It is motivated in part through input prices that depend on transport costs and distance from competing plants, which impact decisions to locate an ethanol plant in a particular county.

The microeconomic theory is based on earlier specifications by Case (1992) and Dubin (1995) who model technology adoption, which has similarities to location decisions, using cross-sectional spatial observations. Utility (expected profit) from the decision is a function of its own characteristics, plus its distance from competitors. Each variable represents the influence plant j has on competing neighboring plants. Results of these studies indicate the intensity of competition impacts expected postadoption profits. Other variables include (among others) the distance from competitors. The expected profit from the decision depends on rivals' decisions and diminishes with distance. The influence of location decisions can be evaluated from the econometric results, in this case on distance. If they are significant, there is spatial interaction and vice versa.

We illustrate the location decision using a simple expected payoff. The expected payoff from a location decision is

$$\prod_{j} = (M \cdot Q_e) - (C(Q_c) + K)$$

where Π_j is the expected payoff for an ethanol plant located at j, M is the gross ethanol crushing margin, Q_e the quantity of ethanol produced and C is processing cost and a function of corn usage, Q_c. K is the annualized capital cost associated with owning the ethanol plant. The ethanol crushing margin reflects impacts of state level subsidies and also depends in part on $(P_c + T_{cj})$ where P_c is the cost of corn (at its origin) and T_{cj} is the shipping cost for corn to location j which depends on distance, and also distance from competing plants at k.

Though more complicated than represented here, the payoff Π_j is affected by the cost of corn procurement and shipping cost which depends on the distance relative to competing plants. A plant would be located at j if $\Pi_j - \Pi_k \geq 0$, for all k. Distance among competitors plays a role in formulating expectations about payoffs in part through the impact of T_{cj} as well as through locations that generate competing payoffs, Π_k.

3.2. Empirical Model Specification

We specify a discrete choice model for the existence of an ethanol plant in a county, which effectively is the result of location decisions. The choice variable is whether an ethanol plant exists in a specific county. Explanatory variables are factors that explain comparative advantages for the plant to locate in a given county. Agricultural characteristics of counties, policy variables, and firm competition are factors that determine payoffs from a plant locating in a given county.

Agricultural characteristics include production and acreage planted to corn as well as other grains (soybean, wheat, barley, sorghum, and sunflower). A Herfindahl index of crop diversification is used as a measure of crop production risk. Different quantities of livestock inventories and feed concentrations are measures of the demand for DDGs. The value of DDGs and the ability to use them locally is crucial as their shipping and logistical requirements are problematic. Finally, states compete vigorously to encourage ethanol plants to locate in their state. Normally, this takes the form of an explicit subsidy, among others. To capture this effect, we include the subsidy to ethanol production, which varies by state. In addition to the above intrinsic characteristics that explain ethanol plant location decisions, there are unobservable factors that impact these location decisions. Although there are many unobservable factors, shipping costs are important and are not available for these products on a cross-sectional basis due to the complexity of intermodal shipping arrangements.

Denoting systematic factors as X_j, the probability that an ethanol plant exists in county *j* is

$$\text{Prob } (Y_j = 1) = F(I_j)$$

where

$$I_j = \alpha + CX_j$$

and if $F(\cdot)$ is a logistic distribution, then

$$\text{Prob } (Y_j = 1) = \frac{\exp(I_j)}{1 + \exp(I_j)}. \tag{1}$$

The indicator function, I_j, in Equation (1), however, ignores that the payoffs from a given location may be correlated to the location of other ethanol plants. The logistic regression with spatial correlation in the choice set below following Sarmiento and Wilson (2005):

$$\begin{aligned} I_j &= \alpha + CX_j + \beta_1 \, SL_j \\ &= \Gamma Z_j(\gamma) \end{aligned} \tag{2}$$

where

$$SL_{-j} = \sum_{k \neq j} D_k \exp(-Dist_{jk}/\gamma),$$

where $Dist_{jk}$ is the distance between plants *j* and *k*. and $D_k = 1$ if an ethanol plant locates in county *k*, and $D_k = 0$ otherwise. The subscript in SL explicitly follows the definition that the spatial index for location j excludes its own location. The probability of an ethanol plant located in county *j* thus depends partly on location of other plants and the distance between competitors. Location factors in X_j, e.g., corn availability, may be further interrelated across counties and depend on the distance between plants. The nonlinear index SL_{-j} is an alternative representation to the product of a weighting matrix and response outcome vector. Klier and McMillen (2008) provide a comprehensive representation of spatial problems in terms of weighting matrixes. The spatial weighting matrix requires use of a bandwidth (dampening) parameter that introduces a nonlinear component (as in our indexes SL_{-j}).

The exponential structure for SL_{-j} follows previous work (McMillen, 1995; Sarmiento & Wilson, 2005). The exponential function allows for a flexible specification of the impact of distance across firms on the response variable through the dampening factor γ. There are other specifications that could have been used for SL_{-j} (e.g., gamma models that include exponential as a special case). Yet, Wand and Jones (1995) show that the shape of the weighting function is more sensitive of the dampener (bandwidth) parameter than to the shape of the density function (e.g., exponential vs. gamma). We thus focus more on the choice of the dampener parameters than in selecting the functional structure of the density function. The negative exponential is commonly used in the literature.

In our application, this dampening factor is estimated (through a likelihood function procedure). The estimated γ determines the importance of distance across ethanol plants on the probability of a plant location. The coefficient γ is determined simultaneously with β_1. The expected coefficient of β_1 is negative—competition will likely reduce incentive to build new plants (after we control for all other factors).

Given the structure for SL_{-j}, the marginal impact of distance among plants on the probability of firm location in region j is

$$\partial \text{Prob}(\text{Plant Location}_j)/\partial D_{jk} = \Lambda_j[1-\Lambda_j]\,[D_k \cdot \exp(-Dist_{jk}/\gamma)\cdot(-\beta_1/\gamma)],$$
$$\text{for } \Lambda_j = \frac{\exp(I_j)}{1+\exp(I_j)},$$

where if $\beta_1 > 0$ and there are decreasing marginal transportation costs ($\gamma > 0$), then the probability of the ethanol plant locating in county j increases with the proximity to other ethanol plants. The opposite effect occurs if $\beta_1 < 0$.

3.3. Spatial Effects of Explanatory Variables

In addition to the spatial lagged dependent variable (or index of concentration of counties across observations in the data) that captures the effect of competition on location choice, the spatial correlation of explanatory variables (e.g., corn) on plant choice captures the interregional impact of that variable. To further capture spatial correlation, we add the following index function to the ethanol plant location decisions:

$$SEL_j = \sum_{k \neq j} \exp(-Dist_{jk}/\gamma)C_k$$

where all other variables are defined as in index (2).

We added a spatial explanatory lagged variable for planted corn acreage to the specification. Thus, the result of ethanol plant location decisions are impacted not only by corn production in the same county but also neighboring counties, and this effect depends on the distance across regions. We also explored spatial lags for the other explanatory variables in the model, but these we not statistically significant in the application.

The dampening parameter γ is assumed the same across spatial index functions in the estimation. It determines the rate at which transportation costs increase with distance. This dampening parameter is then assumed the same for the spatial component of different variables that are embedded in SL and SEL. Equation (2) can thus be further characterized as

$$\begin{aligned} I_j &= \alpha + CX_j + \beta_1 SL_j + \beta_2 SEL_j \\ &= \Gamma Z_j(\gamma) \end{aligned} \tag{3}$$

3.4. Data

We model the probability of location decisions, but do not simultaneously capture complexities related to the timing of these decisions. The analysis was limited by data availability and we used data that could be observed, which is described below. In essence, the decision maker evaluates longer-term characteristics of agriculture in each county (based on averages described below). Ideally, we would have contemporaneous decisions regarding location decisions (not when the plant begins operating), but this data is not available. Based on this and other contemporaneously observed variables the decision maker evaluates the expected value of the payoff. However, we do not observe the payoff, but do observe the result of the location decisions which is a binary variable.

The right-hand side variables consist of a data set of county-level observations that were treated as average values derived over the period 1995–2005. In total there are 2,979 observations. The data were assembled on a county basis and was taken from several sources. Ethanol plant locations were taken from the Renewable Fuels Association (2006) records and supplemented with data from *Ethanol Producer Magazine* (2006). Agricultural data, including area planted and yields for corn, soybeans, and wheat, were obtained from the National Agricultural

TABLE 1. Summary Statistics

Variable	*M*	*SD*	Min	Max
Corn yield (bu/a)	69	50	0	228
Yields of other crops (bu/a)	47	30	0	156
Planted acreage corn (acres)	26,235	45,014	0	330,000
Planted acreage total (acres)	77,778	132,446	0	905,377
Herfindahl index	0.20	0.33	0	1
Total livestock feed demand (000 tons)	5,383	4,058	0	13,533
Ethanol subsidy ($/gallon)	0.003	0.005	0	0.3
Cattle on feed (000 head)	524	888	0	2,743
Hogs on feed (000 head)	1,904	3,179	0	15,090

Statistics Service (NASS; 1995–2005) by county. Livestock inventories by state (county) were also taken from NASS. In addition, we experimented with livestock feed concentrates obtained from *Feed Management* (1994–2004) and available only on a state basis, as well as a proxy for feed use by ProExporter (2007). However, the latter were not significant and were deleted. Distances are derived among plants using geographic information system (GIS) procedures.

Finally, the amount of subsidy to ethanol production was derived for each state. A federal subsidy exists, but is common across all states and hence should have a neutral impact on location decisions. However, individual states compete vigorously for ethanol plants, and normally this takes the form of a subsidy paid to plants located in their states. Values for this variable were obtained from ProExporter (2006). States with specific ethanol subsidies are South Dakota and Kansas (3 cents/gallon); Nebraska (7 cents/gallon); and Minnesota, Missouri, and Wisconsin (8 cents/gallon).

A statistical summary of the important variables is contained in Table 1. Of interest are corn yields per county, which ranged from 0 to 228 bu/a. Planted acreage for corn per county ranged from 0 to 330,000 acres. Cattle and hogs on feed average 524,000 and 1,904,000 head per county, respectively. Finally, total livestock feed demand averaged 5,383,000 tons per county.

3.5. Estimation

In the spatial indexes in Equation (3) of the discrete choice model with spatial correlation, distance enters nonlinearly because of uneven frequencies when defining lags in a spatial framework. Software designed to estimate dichotomous choice models with spatial correlation data does not exist (to our knowledge). Sarmiento and Wilson (2005) thus developed a procedure to estimate the discrete choice of plant location with an algorithm that converges easily. The algorithm is developed based on concentrating the logistic likelihood function in terms of the nonlinear coefficient in the spatial correlation function (Sarmiento & Wilson, 2005, 2007). That algorithm is used in this study. In particular, the estimator of Equation (1) with the index function in Equation (3) is obtained by solving the optimization:

$$\begin{gathered}\underset{\gamma}{\operatorname{Max}}\ \ln \mathrm{L}(\gamma) \\ \text{s.t.}\ \sum_i (\gamma_i - \Lambda_i) Z_i(\gamma) = 0\end{gathered} \tag{4}$$

where

$$\ln L(\gamma) = \sum_i y_i \ln\{\Lambda_j\} + \sum_i (1 - y_i) \ln\{\Lambda_j\}$$

and

$$y_i = 0 \quad \text{or} \quad y_i = 1.$$

Convergence of the algorithm was estimated using GAUSS to solve the nonlinear logit model in Equation (4). Application of the algorithm yields convergence at $\gamma = 9$. The likelihood function is concave with respect to γ; it is maximized at $\gamma = 9$ with a likelihood of 393.7. At $\gamma = 3$ and $\gamma = 20$ the likelihood function is 396 and with no spatial correlation the likelihood function is 397. The spatial correlation component is statistically significant. Implementation of the algorithm in Equation (4) reduces the problem to a one dimensional optimization problem that can be solved using a grid search. In our application, the likelihood function is concave with respect to γ that result in a global maximum.

Overall, the advantage of a concentrating likelihood function with respect to γ is that it allows an algorithm that easily converges and is easily implemented. In contrast, full information maximum likelihood (FIML) generally embeds an algorithm that does not easily converge to global maximum. Difficulties in implementing FIML under nonlinear in parameters models are well documented in the literature (e.g., Klier & McMillen, 2008). In our application, the algorithm under a concentrated likelihood function easily converges using a process that avoids difficulties of estimation of a highly nonlinear in parameter structure under FIML. An alternative is the linearized spatial logit model by Klier and McMillen (2008). That model uses a 2-stage estimator to generate an approximation to the full information maximum likelihood (FIML) estimator. We instead adopted the concentrated likelihood approach that is asymptotically equivalent to FIML as well as easy to implement.

A shortcoming of the concentrated likelihood approach is that the standard errors are conditional on γ. Yet, the parameter estimates and estimates of the variance of the coefficient estimates are consistent estimators under the concentrated likelihood function approach. FIMLstandard errors can also be calculated using concentrated likelihood function estimates. Moreover, while under the concentrated likelihood approach we do not have an estimate of the standard error of γ, we can still test hypothesis on γ using the likelihood ratio test.

4. ANALYSIS OF RESULTS

4.1 Econometric Results

The estimated scale parameter γ has an insightful economic interpretation. It shows that the degree of firm interrelation increasingly intensifies as firms are more closely located to each other. The value of γ indicates the rate at which interrelation across firms decreases with distance. A positive value for γ is consistent with the premise that transportation costs increase at a decreasing rate. A negative γ implies that correlation across firms is larger when firms are further located from each other—which is not reasonable. A positive γ in ethanol locations indicates that the effect of competition on location decisions is more intense when plants are more closely located.

Other econometric results are shown in Table 2. Several of the agricultural variables are highly significant. Corn yield is not significant, but counties with higher yields of other crops have a lower likelihood of having an ethanol plant (i.e., counties with higher yields of other crops have a lower likelihood to have an ethanol plant). Of interest are that total planted acres and acres planted to corn have positive and statistically significant effects on ethanol plant locations. Simply, counties with more planted area in total reflecting in part CRP effects (the CRP program takes land out of production) more area planted to corn[1] and lower yields of competing crops, have a greater likelihood of ethanol plants being located in that county. Crop production risk (Herfindahl index) has no explanatory effect on plant location (consistent with Sarmiento & Wilson, 2005). In the model specification, we also explored including the price of

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[1] The corn acreage planted is an important variable to control for county scale (or size). We thus capture county heterogeneity (in terms of county size) for ethanol production by incorporating the variable of corn acreage planted, which is the most important proxy for county size in terms of ethanol production.

TABLE 2. Ethanol Location Model With Spatial Effects

	Coefficient	*SE*	*t* Value	Derivative × Variable Mean Value
Constant term	−4.8128	0.323	−14.90	N.A.
Corn yield	0.0006	0.0014	0.43	0.0100
Yields of other crops	−0.0019	0.0013	−1.51	−0.0487
Planted acreage corn	0.2599	0.0932	2.79	0.0338
Planted acreage total	0.1037	0.0451	2.30	0.0400
Herfindahl index	0.2625	0.6250	0.42	0.0025
Total livestock feed Demand	0.0000	0.0000	−0.89	−0.0109
Ethanol subsidy $/gallon	3.9787	1.1948	3.33	0.0049
Cattle on feed	0.0004	0.0002	2.29	0.0112
Hogs on feed	0.0001	0.0000	2.65	0.0097
Spatial competition	−22.5969	8.3692	−2.70	−0.0123
Corn spatial lag	0.0001	0.0000	2.51	0.0075
Log likelihood			−393.7	

Note. N.A. = Not applicable; * = change in the probability from percentage change in the explanatory variable.

corn in each county, but the price effects were not significant when having the crop yield of the county in the model.

Some of the values are interesting. As an example, a 1% greater corn yield for a county leads to a 1% increase in the probability of that county having an ethanol plant. In contrast, a 1% increase in the yield of other crops leads to a 0.55% decrease in the probability of that county to having an ethanol plant. Also, an increase of 1% in cattle on feed in that county yields a 1.1% increase in the probability of that county having an ethanol plant. Other marginal effects in Table 2 can be interpreted similarly.

The impact of livestock is important. Both cattle and hogs in county *j* have a positive effect on plant locations in that county. We experimented with different measures of feed concentrate demands, but these results were not significant. The results are largely a reflection of the prospective local demand for feeding of DDGs, the ethanol byproduct. DDGs have difficult shipping and logistical requirements and hence the ability to feed them near the point of ethanol production is important. These results explain why there are concentrations of ethanol production in regions that have large livestock inventories, including dominant feeding regions without corn production (e.g., Texas). The results also show that both cattle and hogs on feed are important, but the elasticity of the former is greater. This reflects that cattle have a greater ability to consume DDGs than other species.

The results show that the effect of state subsidies is positive, as expected, and its explanatory power is significant. The quantitative effect of the subsidy is illustrated in Figure 1. Simply, assuming all else is constant, a greater subsidy increases the probability of a plant being located in a county in that state. Some states (e.g., Minnesota, Nebraska, among others) have made extensive use of subsidies to attract plants. These results show that a 12 cent/gallon subsidy by a state increases the probability of locating in that state by about 3%. However, subsidies alone will not attract investment and at higher levels, the confidence interval increases. A large production of corn to supply the plant and livestock inventories to absorb the DDGs is also important.

Spatial impacts are important, and if not included in the econometric analysis, would result in a misunderstanding of the location decisions. Two spatial impacts are important in explaining ethanol plant location decisions. One form of spatial interdependence is distance to competing plants. We refer to this as spatial competition, and it has a negative impact on local plant development. The effect of the existence of competing plants is negative, and its effect sharply decreases with distance. Figure 2 shows the effects of competition on the probability that a plant locates in a given county.

The results show that within about 30 miles the interplant spatial competition is important and reduces the likelihood of locating within that range. For example, there is a 3% lower likelihood to have an ethanol plant if there is another plant within a 30-mile radius. At 60+

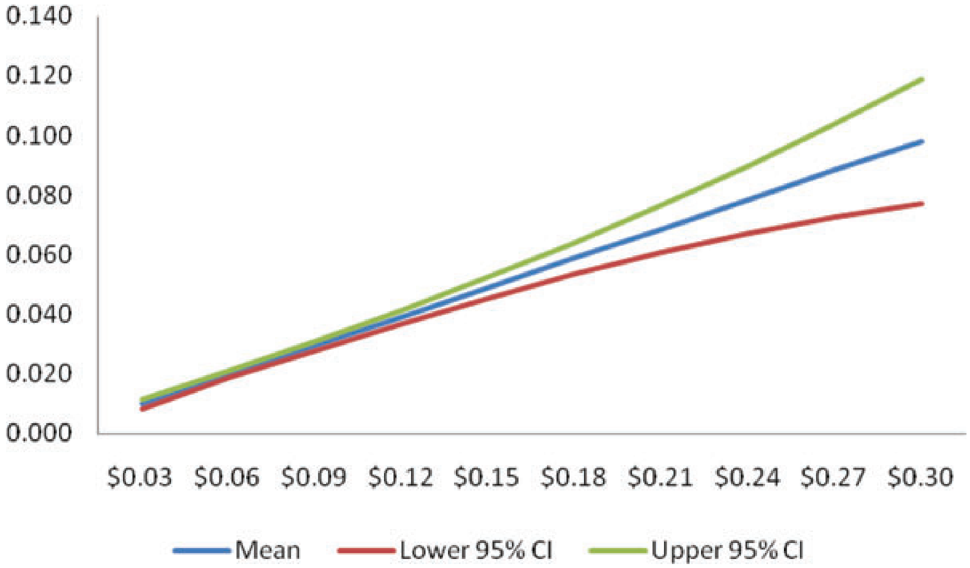

Figure 1 Change in Probability of Plant Location Due to State Subsidy ($per gallon).

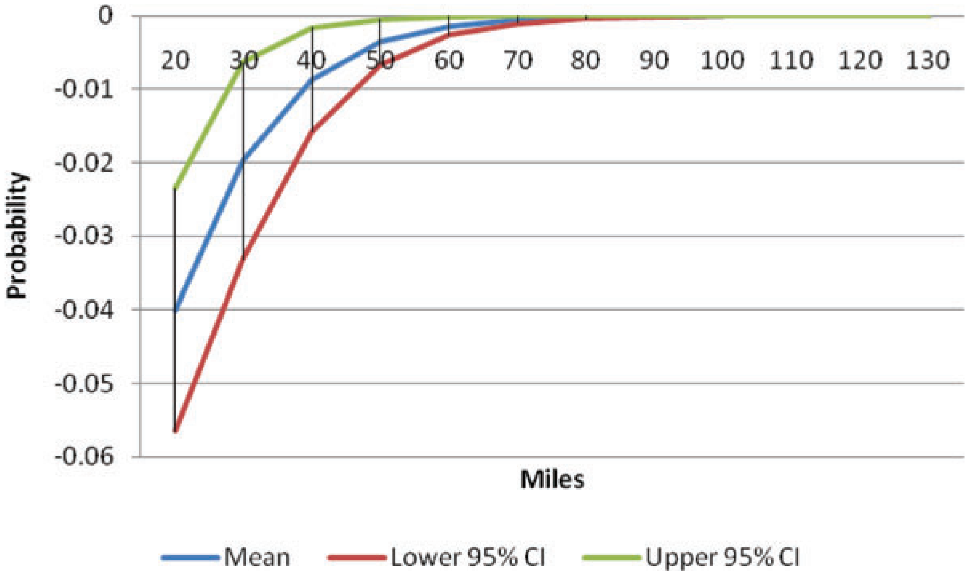

Figure 2 Change in Probability of Plant Location due to Competition, by Distance.

miles apart, the impact on the probability of location in county *j* is near nil. Thus, existence of competition decreases the probability of building a plant in that county, when controlling for other effects, and this impact decreases with distance. This value quantifies the impact of competitor plants in the county and the spatial autocorrelation of competitor plants. The result indicates that existence of competitor plants reduces the likelihood of de novo ethanol plant locations. This is expected and no doubt is reflective of the new plant's desire to want to avoid competition in procurement with incumbent plants.

The other is the spatial lag with respect to corn production. Among the explanatory variables, acreage planted to corn was the only effect that has a statistically significant spatial lag. Results indicate that the spatial externalities in county *j* (neighboring counties' corn production) have a positive effect on ethanol plant development in county *j* and this effect depends on the distance between the counties. This result is important. An ethanol plant location decision is impacted not only by corn production in its own county, but also by corn production in neighboring counties. This likely is a result of the need to procure corn from more than the county in which the plant is located, but also from neighboring counties, all of which impact the expected payoff in comparing location decisions.

4.2 Interpretation of Probabilities

The model is used to illustrate the probability of ethanol plant location decisions. To do so, we use the values of the right-hand side variables for each observation. From these, we generate the predicted probability. These are shown in Figure 3 where the shading reflects the probabilities of a plant existing in that county. In addition, we overlay existing plants on these probabilities.

The results show the effects of the critical variables and illustrate a fairly intense probability of location in the traditional high corn-producing regions (e.g., Iowa and Illinois). It also shows that in states with greater state subsidies, in addition to large corn production (e.g., Minnesota, Nebraska), the probabilities of location are larger. Finally, it shows that in some regions with extensive livestock feeding (e.g., Texas, California) there is a higher probability of a plant location even though these regions have neither extensive corn production nor state subsidies.

5. SUMMARY AND IMPLICATIONS

Ethanol production is one of the fastest growing industries in the United States. The growing demand for ethanol has resulted in mammoth investments in value-added agriculture and

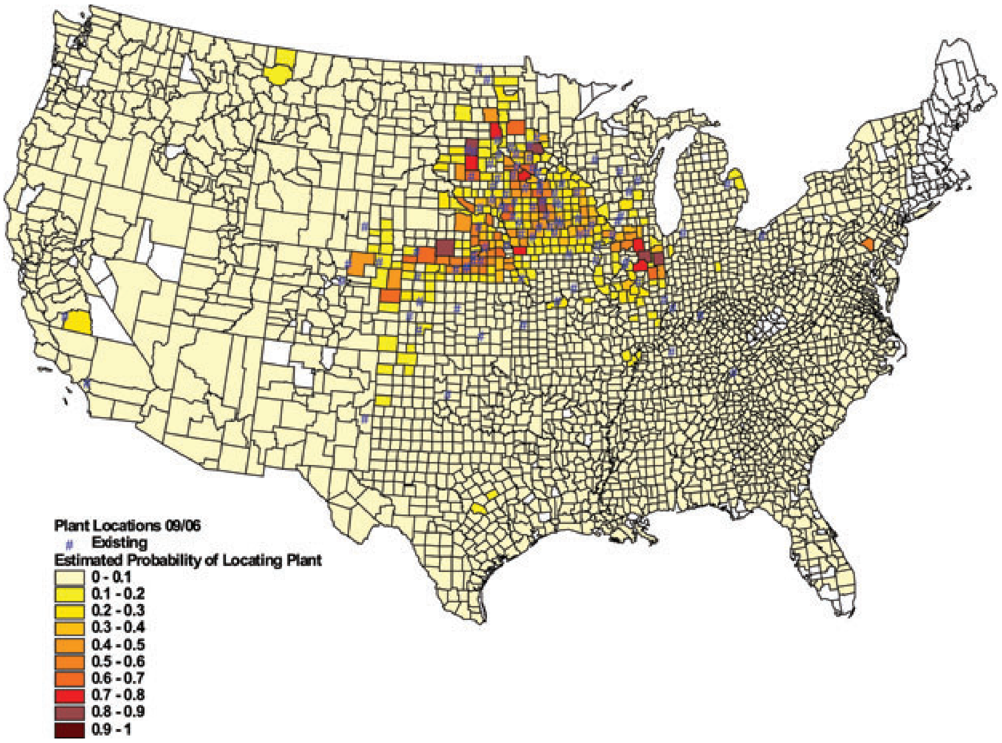

Figure 3 Probability of Plant Location with Existing Plant Locations.

intense competition among states to attract ethanol plants. The purpose of this study is to analyze and determine factors that impact where ethanol plants are located. The analysis uses a discrete logit model of location decisions by new ethanol plants and is specified and estimated using spatial autocorrelation techniques. This allows an explicit specification to capture spatial impacts on the dependent variable. In addition to the spatial autocorrelation and interdependencies, the model includes other agricultural variables and state-level subsidies.

The results indicate that location decisions are impacted by agricultural characteristics of a county, competition, and state-level subsidies. Notably, counties with large areas planted to corn, lower yields of competing crops, and larger cattle inventories are more likely to attract a new ethanol plant. These decisions are also impacted by spatial competition in two forms. One is the spatial lag of corn production in neighboring counties. This suggests that ethanol plant location decisions are impacted by corn production within the county as well as in neighboring counties. The second is spatial relations among competitors. Simply, the existence of a competing ethanol plant reduces the likelihood of making a positive location decision, and this impact decreases with distance. Finally, state-level subsidies are significant and a very important variable impacting ethanol location decisions.

These results have important private and public sector implications. From a private location decision perspective, these results clearly indicate there are a multitude of factors impacting location decisions. Corn supplies are very important, as well as competing crops. In addition, cattle/hog inventories are important as a source of feed demand for the byproduct DDGs. As a result, one can expect ethanol plant locations to be concentrated primarily in counties with large corn production and/or in counties with large cattle/hog inventories. Indeed, this is what is being observed with heavy concentration in corn-producing states (Iowa, Illinois, Nebraska, and Minnesota) and in counties in Texas that are heavy feeders. Finally, competing ethanol plants are important and detract from further expansion. This impact is not only local within a county, but has a spatial dimension as well.

There are also public sector implications. At least six states have programs to entice ethanol plants. Our results suggest these programs are effective. Certainly, states such as Minnesota, South Dakota, and Nebraska, each of which have ethanol subsidies, have a large number of ethanol plants. However, other factors such as corn production and cattle inventories are important and in some states are not dominated by the state subsidy.

Finally, the logit model with spatial correlation in the choice set used in this study is useful not only in the ethanol sector, but could be applied in many other sectors. For most of these industries, spatial impacts of competition and procurement are important, and ignoring them would result in biased estimates and a misunderstanding of factors that impact these decisions. As shown here, the spatial impacts are important to understanding these types of spatial location decisions. An important area of future work is simultaneous modeling of random effects and spatial correlation to model firm location decision, but to do so would require a highly complex solution algorithm given both the discrete and spatial autocorrelation of the problem.

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