Geographic Competition in the Retail Gasoline Market: Who are a gas station's competitors?

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ABSTRACT. Volatility in gasoline prices often leads the public to question the competitiveness of gasoline markets in the US. However, the retail gasoline market has received less examination in the literature in part because the market exhibits characteristics consistent with a competitive market. The retail gasoline market consists of numerous stations selling a homogeneous product to price conscious consumers. Competitive pressures are heightened further by the prominent posting of prices lowering consumers' cost of obtaining price information. The assumption of a competitive market however ignores the spatial differentiation that results when consumers incur travel costs. By giving individual firms pricing power, spatial differentiation creates the potential for competing firms to engage in strategic interaction in their pricing decision. This study uses spatial econometrics to examine the extent to which this product differentiation results in strategic interaction in the pricing decision of retail gas stations. Results indicate that gas stations engage in strategic interaction with neighboring stations when setting prices and specification tests suggest that the each station considers the behavior of its fifteen nearest competitors. (R3, L1)

I. Introduction

Volatility in gasoline prices often leads the public to question the competitiveness of gasoline markets in the US. However, the retail gasoline market has received less scrutiny in the literature than the exploration and wholesale markets in part because the retail market exhibits characteristics consistent with a competitive market. The retail gasoline market consists of numerous stations selling a homogeneous product to price conscious consumers. Competitive pressures are heightened further by the prominent posting of prices lowering consumers' cost of obtaining price information. The assumption of a competitive market however ignores the spatial differentiation that results when consumers incur travel costs. By giving individual firms pricing power, spatial differentiation creates the potential for competing firms to engage in strategic interaction in their pricing decision. This study uses spatial econometrics to examine the extent to which this product

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differentiating results in strategic interaction in the pricing decision of retail gas stations.

Whereas spatial econometrics is used extensively in the fields of public and urban economics to test for the existence of strategic interaction between economic agents in close proximity, there is less research outside of these fields examining strategic interaction between geographically close firms. In contrast to standard estimation techniques, the methodology controls for the inherent endogeneity that is present when strategic interaction exists. This paper utilizes spatial econometric methods to test for the existence of strategic interaction between retail gas stations in the Houston metropolitan area. Since the primary form of product differentiation in the retail gasoline market is location, this market is an ideal market to test for the presence of strategic interaction. Results indicate that gas stations engage in strategic interaction with neighboring stations when setting prices and specification tests suggest that the each station considers the behavior of its fifteen nearest competitors.

The next section of the paper reviews the relevant literature on strategic interaction. Section III presents the theoretical model on which the paper is based and Section IV discusses the data used in the study. The empirical specification and results are described in Section V. The final section offers conclusions.

II. Literature Review

In the field of public economics, spatial econometrics has been widely used to test theoretical models of interjurisdictional competition. Heyndels and Vuchelen (1998), Brueckner and Saavedra (2001), Brett and Pinske (2000) and Buettner (2001) find evidence of strategic interaction in the setting of state and municipal tax rates. Spatial econometrics has also been used to test the yardstick competition model, in which mobile residents use government expenditures as a proxy for efficient provision of a public good. Case et al. (1993) found strategic interaction between neighboring states' expenditure decisions and Bivand and Szymanski (2000) found strategic interaction in garbage collection expenditures by English districts. Byrne (2005) examined strategic interaction in the use of tax increment financing as an economic development tool and found evidence that municipalities' use of the incentive was partially a result of competition between neighboring municipalities.

In addition to testing for strategic interaction in the setting of tax rates and expenditure levels, the methodology has also been applied to policy decisions. Brueckner (1998) examined California municipalities' adoption of growth controls and found that a municipality was more likely to adopt growth controls when neighboring municipalities also adopted growth controls. Murdoch, Sandlet, and Sargent (1997) and Fredriksson and Millimet (2002) examined the implementation of environmental policies at the national and state level, respectively. Saavedra (2000) found a race to the bottom in the setting of welfare benefits as one state's lowering of benefits induced neighboring states to lower benefits as well. Rincke (2006, 2007) found the presence of strategic interaction in school districts' decisions to allow intra-district transfers and open charter schools.

A large portion of the empirical literature on gasoline markets has focused on the inter-temporal responsiveness of retail prices to changes in wholesale gasoline and oil prices. Much of the research has found an asymmetric response in retail gasoline prices. Although results are mixed the "rockets and feathers" phenomenon suggests that retail prices respond more quickly to increases in crude oil and wholesale prices than to decreases. Bacon (1991), Duffy-Deno (1996), Borenstein et al. (1997) and Galeotti et al. (2003) find evidence of asymmetric price responses at the retail level, whereas Karrenbrock (1991), Reilly and Witt (1998) and Bachmeier and Griffin (2003) fail to find evidence of asymmetric price responses.

The literature on inter-station pricing, which follows closely to this paper, models the retail gasoline market as an imperfectly competitive market in which equilibrium prices are determined by each firm's own characteristics and local demand characteristics. Barron et al. (2000) include local household income and gasoline brand as determinants of station prices and found that both influence prices with higher local income leading to increased prices. Barron et al. (2004) replaced local demand characteristics with station attributes, such as the number of pumps and the presence of a service station and found that these attributes along with gasoline brands influenced gasoline prices. Hosken et al. (2008) included commuting time and population measures along with income as local demand characteristics and found that increased commuting and population led to lower prices. Each of these studies on inter-station pricing included distance to the nearest gas station as a spatial component to pricing with Barron et al. (2000) being the only study that found the variable to have a statistically significant impact on price. However, these studies do not explicitly take into account the endogeneity present when prices are jointly determined in a market exhibiting spatial interdependence.[1] Haining (1983) represents an early attempt to test strategic pricing in the retail gasoline market. Haining tested for a spatial process in the relatively small sub-market of 87 stations in S.W. Sheffield, England but failed to find consistent evidence of strategic interaction. The lack of consistency in the results may be due to the relatively small sample size along with the limited amount of explanatory variables used in the model, which, as discussed below can be particularly problematic if the missing variables contain a spatial process.

Just as spatial econometrics is used by public economists to test whether jurisdictions compete for mobile businesses and residents the methodology can also be useful in determining the extent to which businesses in close proximity compete with one another. Nonetheless, the application of spatial econometrics beyond the fields of public economics and regional science has been limited. Recent papers that have used the methodology test for strategic interaction between firms include Mobley (2003), which tested for strategic interaction in hospital pricing and Kalnins (2003), which tested for strategic interaction in hamburger pricing. Mobley found evidence of strategic interaction between nearby hospitals whereas Kalnins did not find evidence of strategic interaction between hamburger chains.

III. Model

Absent strategic interaction a firm's pricing decision is determined by maximizing the profit function

$$\pi = PQ - C(Q) \tag{1}$$

where $C(Q)$ is the firm's costs as a function of output. In perfectly competitive markets, price-taking firms maximize profits by producing at the output where $C'(Q)$ equals the market clearing price. However, in markets characterized by product differentiation, firms face a downward sloping demand curve and the profit maximizing price is found by replacing Q in equation 1 with the firm's demand function, $Q(P)$, and differentiating with respect to price. In the retail gasoline market the physical attributes of each firm's output is homogeneous, however, the location of each station creates a differentiated product for consumers who save on travel costs when purchasing at nearby stations. Assuming a linear demand function of the form $Q(P) = \alpha_1 - \alpha_2 P + \theta Z$, where Z is a matrix of demand determinants and a cost function of the form $C(Q(P)) = \varphi + \delta Q(P)$, where φ is a fixed cost and δ is the constant marginal cost of gasoline, the reduced form equation for the profit maximizing price, P^*, is

$$P^* = \frac{\alpha_1}{2\alpha_2} + \frac{1}{2}\delta + \frac{\theta}{2\alpha_2} Z . \tag{2}$$

The decision making process becomes more complex in the presence of strategic interaction. In this scenario, the firm's pricing decision is dependent on both its characteristics and on the pricing decision of its competitors. Following a Bertrand model with product differentiation, consider the case in which the market consists of two firms, a and b. Assuming linear demand and cost functions, firm a's demand is $Q_a = \alpha_1 - \alpha_2 P_a + \alpha_3 P_b + \theta Z_a$ and its costs are $C_a = \varphi_a + \delta_a Q_a$. Firm a's profit maximizing price takes the form of a reaction function (R_a), which is dependent on firm b's pricing decision:

$$R_a = \beta_1 + \frac{1}{2}\delta_a + \beta_2 Z_a + \rho P_b \tag{3}$$

where , $\beta_1 = \dfrac{\alpha_1}{2\alpha_2}$, $\beta_2 = \dfrac{\theta}{2\alpha_2}$ and $\rho = \dfrac{\alpha_3}{2\alpha_2}$. Assuming symmetry, firm b's reaction function is

$$R_b = \beta_1 + \frac{1}{2}\delta_b + \beta_2 Z_b + \rho P_a \tag{4}$$

As long as the slope of the reaction functions, ρ, is less than one a Nash equilibrium exists at the intersection of the two reaction functions as shown in Figure 1.

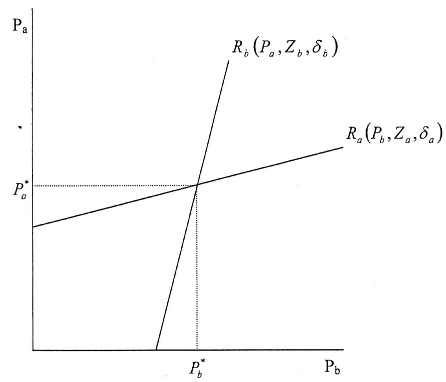

Figure 1. Reaction Functions

Solving for the profit maximizing price, P_a^*, shows that the presence of strategic interaction results in firm *a*'s profit maximizing price being dependent on both its characteristics (δ_a, Z_a) and the characteristics of its competitor (δ_b, Z_b).

$$P_a^* = \frac{\beta_1 + \frac{1}{2}\delta_a + \beta_2 Z_a + \rho\left(\beta_1 + \frac{1}{2}\delta_b + \beta_2 Z_b\right)}{\left(1-\rho^2\right)}. \tag{5}$$

Likewise firm *b*'s profit maximizing price is determined by both its characteristics and the characteristics of its competitor.

$$P_b^* = \frac{\beta_1 + \frac{1}{2}\delta_b + \beta_2 Z_b + \rho\left(\beta_1 + \frac{1}{2}\delta_a + \beta_2 Z_a\right)}{\left(1-\rho^2\right)} \tag{6}$$

The slope of the reaction functions, ρ, indicate the strength of the strategic interaction between neighboring firms. Figure 2 illustrates how the magnitude of the strategic interaction impacts pricing. The solid lines correspond to a scenario of relatively weak strategic interaction between the two firms and the dotted lines correspond to a scenario of relatively strong strategic interaction between the two firms. In both scenarios the initial pricing equilibrium occurs at $\left(P_a^0, P_b^0\right)$.

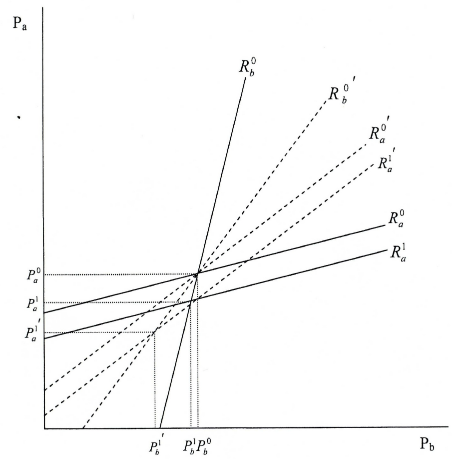

Figure 2. Reaction Functions

Notes: Reaction functions R_a^0, R_a^1, and R_b^0 correspond to a scenario of relatively weak strategic interaction and reaction functions $R_a^{0}{}'$, $R_a^{1}{}'$, $R_b^{0}{}'$ correspond to a scenario of relatively strong strategic interaction.

Suppose firm *a*'s marginal cost decreases causing a downward shift in its reaction function from R_a^0 to R_a^1 in the case of weak strategic interaction and from $R_a^{0\prime}$ to $R_a^{1\prime}$ in the case of strong strategic interaction. In both cases the downward shift of firm *a*'s reaction function is of the same magnitude and the Nash equilibrium price falls under both scenarios. However in the case where strategic interaction between firms is strong, the steep reaction curves result in a greater decrease in prices. Whereas equilibrium prices fall from $\left(P_a^0, P_b^0\right)$ to $\left(P_a^1, P_b^1\right)$ in the case of weak strategic interaction, in the case of strong strategic interaction prices fall from $\left(P_a^0, P_b^0\right)$ to $\left(P_a^{1\prime}, P_b^{1\prime}\right)$.

A. SPATIAL LAG MODEL

The empirical model of N-firms in a monopolistically competitive gasoline market without strategic interaction can be estimated via OLS through the equation

$$y_i = \beta X_i + \varepsilon. \tag{7}$$

where y_i is station i's profit-maximizing price and X_i is a vector of the station's characteristics that includes a constant, demand determinants of potential customers and the marginal cost of gasoline. Whereas in the previous section strategic interaction consisted of two firms simultaneously setting price while taking into account its competitor's reaction function, the empirical model represents a market where multiple firms simultaneously set prices while taking into account the reaction functions of its many competitors. The Nash equilibrium prices in this expanded market is estimated by the spatial lag model

$$y_i = \rho \sum_{j=1}^{N} w_{ij} y_j + \beta X_i + \varepsilon_i \tag{8}$$

$\rho \sum_{j=1}^{N} w_{ij} y_j$ models the manner in which a firm's pricing decision is influenced by its competitors' prices. w_{ij} are the weights that determine the pattern of interaction between firms and essentially defines the spatial market. If firm i considers firm j's pricing decision when setting price w_{ij} is greater than zero defining j as i's competitor. When firm i does not regard j as a competitor w_{ij} equals zero. Consider the case where neighboring stations are defined as stations located within 2 miles of each other. If stations i and j are located within 2 miles of each other then $w_{ij} > 0$ and if stations i and j are located more than 2 miles apart, $w_{ij} = 0$. It should be noted that the weighting scheme must be determined a priori, therefore, the model is estimated using various weighting schemes with goodness of fit measures and specification tests used to determine the weighting scheme that best approximates actual the strategic interaction between gas stations. The spatial lag parameter ρ represents the strength of the interaction between competing firms and is analogous to slope of the reaction function in the two-firm model. However, in the N-firm model ρ gives the change in a firm's best response due to a change in the spatially weighted average of competitors' prices, $\sum_{j=1}^{N} w_{ij} y_j$, as opposed to a change in a single competitor's price. The resulting endogeneity from the simultaneous setting of prices in the spatial lag model can be seen by writing equation (8) in matrix form:

$$y = \rho W y + \beta X + \varepsilon \tag{9}$$

As described above the N x N weights matrix W takes the value of zero for the diagonal elements (i.e. w_{ii}), non-zero values for the off-diagonals in which two firms are considered neighbors and zero for the off-diagonals in which firm i does not consider firm j's pricing decision.

The importance of taking into account the unique spatial nature of firms' strategic behavior can be seen by rearranging equation 9 so that the dependent variable is on the LHS.

$$y = \left(I = \rho W\right)^{-1} \beta X + \left(I - \rho W\right)^{-1} \varepsilon \tag{10}$$

As one can see, the endogeneity of firm decision making has two significant impacts. First, each firm is influenced by all other firms in the sample, even those which are not defined as neighbors. Suppose a gas station only considers the behavior of its three closest neighbors. Each of its neighbors considers the behavior of their three closest neighbors, who in turn consider the behavior of their three closest neighbors and so on. Hence, the original gas station's price is influenced by all stations who are neighbors to its neighbors with less and less weight being assigned to competing stations based on the "degrees of separation." The second consequence of this simultaneity is that each element of y is correlated with each element of ε making estimates of ρ and β inconsistent. Spatial econometric techniques are used to control for the spatial process and this paper uses a maximum likelihood estimation developed by Anselin (1988).

Omitted variables gives rise to additional issues in the spatial lag model. If an omitted variable exhibits spatial dependence then our assumption that ε_i is independent across locations is violated. In this case, the error term is of the form

$$\varepsilon = \nu\varepsilon + \eta \tag{11}$$

where η is a well behaved error term and ν is the combined spatial dependence from spatially correlated omitted variables, analogous to ρ in equation 9. The spatially correlated omitted variables is particularly problematic when estimating equation 9 as even in the absence of strategic interaction (ρ=0) the presence of these omitted variables can result in a spurious finding of spatial dependence in y. A Lagrange Multiplier test (Anselin et al. 1996) is used to test for the presence of spatially correlated omitted variables.

IV. Data

The primary data source for this paper is a dataset of branded retail gas stations in the Houston metropolitan area. This dataset of 689 gas stations contains retail prices for the second week of February 2001 along with the brand and address of the station.[2] Using GIS software, an electronic map was created in order to generate distance weights based on the longitudinal and latitudinal locations of firms. Twenty-six observations had missing, incomplete or unclear addresses resulting in a final sample of 663 gas stations. In addition to price and location, the dataset also includes the brand of gasoline sold at each station. There are ten different brands of gasoline. Four brands with only a handful of stations were combined into one category, *OTHER*. Dummy variables for the brand of gasoline are used to control for cost differences between the different brands. Since stations under the same brand purchase gasoline from their respective brand's wholesaler, these dummy variables should capture any variation in a station's marginal cost of gasoline.

The demand determinants, *Z*, were created by assigning each observation the characteristics of the census tract in which the station is located. The variables used to control for localized consumer demand are mean household income (*INCOME*), percent of commuters driving to work (*%DRIVE*), population density (*POPDENS*), percent of households with children present (*%CHILD*) and percent of population that is male (*%MALE*). Assuming gasoline is a normal good, increased income and population density should increase the demand for gasoline resulting is positive coefficients for *INCOME* and *POPDENS.*[3] *%MALE* is included in the regressions to control for a potential gender differences in the demand for gasoline. Although *%DRIVE* may point to an area's propensity to consume more gasoline per capita, an individual firm's pricing power comes from locational differentiation, resulting in the station's ability to offer travel cost savings for customers who purchase an otherwise homogeneous product. More automobile commuters indicates a more mobile population that can purchase gasoline at numerous stations along commuting routes while incurring negligible travel cost resulting in a more elastic firm demand. For this reason, the coefficient of *%DRIVE* is expected to be negative. *%CHILD* could have either a positive or negative impact on the price of gasoline. The presence of children would require households to make more automobile trips in the course of a typical day. This increased number of trips results in a higher demand, and thus price, for gasoline in general. However, as a result of the increased trips these households are exposed to a larger number of low-travel-cost purchasing opportunities. Similar to commuters, these opportunities increase a household's sensitivity to changes in local gasoline prices, which would result in a negative coefficient for *%CHILD*.[4] Figure 3 shows the location of each gas station within the Houston metropolitan area along with the corresponding census tracts.

Figure 3. Gasoline Stations and Census Tracts

Notes: Dots indicate the location of each gas station within the Houston metropolitan area along with the corresponding census tracts.

Table 1 shows the summary statistics for the sample. The mean price is \$1.393 with a standard deviation of \$0.049. The highest price is the sample is $1.648 and the lowest price is $1.219. The considerable variation in prices indicates that the retail gasoline market is not perfectly competitive. The variation in prices exists not only at the market level but also within brands as shown in Table 2 and Figure 4. Table 2 shows that the standard deviation of prices within brands ranges from $0.028 for Conoco branded stations to $0.065 for Chevron stations. Figure 4 shows a more detailed illustration of the variation with a scatterplot of gasoline prices by brand.

TABLE 1–Summary Statistics

Variable	Definition	Mean	Standard Deviation	Maximum	Minimum
PRICE	Average gasoline price ($/gallon)	1.393	0.049	1.648	1.219
INCOME	Mean household income ($1,000s)	55.61	28.09	265.42	16.77
%DRIVE	Percent of commuters who drive to work	88.77	7.33	98.92	41.09
%CHILD	Percent of household with children present	42.14	14.37	65.68	1.84
POPDENS	Population per acre	7.50	5.54	50.88	0.14
%MALE	Percent of population male	50.04	3.11	73.26	41.27

TABLE 2–Summary Statistics of Price by Brand

Brand	Observations	Mean	Standard Deviation
Chevron	137	1.401	0.065
Citgo	43	1.385	0.031
Conoco	106	1.373	0.028
Phillips 66	45	1.366	0.029
Shell	114	1.397	0.053
Texaco	192	1.406	0.043
Other	26	1.379	0.042

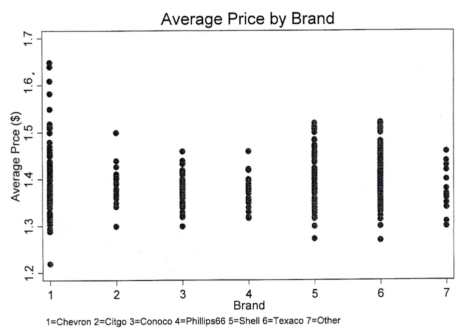

Figure 4. Scatterplot of Price by Brand

V. Empirical Model

A. DETERMINING A STATION'S COMPETITORS

As mentioned above, testing for strategic interaction requires that the weights w_{ij} be determined a priori. At the heart of this issue are prior beliefs on how the economic agents interact with one another. For this paper, the spatial lag model is estimated using *k*-nearest neighbors weighting schemes and distance based weighting schemes. For the first weighting schemes, firms place an equal weight on the pricing decision of their *k*-nearest competitors and a weight of zero on all other competitors. For the second scheme, the weight placed on competing stations' pricing decision is a function of the distance between the stations. In this setup weights take the form of:

$$w_{ij} = \begin{cases} f(d_{ij}) & \text{if } d_{ij} < d^* \\ 0 & \text{if } d_{ij} \geq d^* \end{cases}$$

where w_{ij} is the weight given by firm *i* to firm *j*'s pricing decision, d_{ij} is measured as the distance between stations *i* and *j*, $f(d_{ij})$ is a distance based function and d^* is the cutoff distance beyond which w_{ij} equals zero.

The spatial lag model is estimated with *k*-nearest neighbors weights for *k*=5, 10, 15, 20 and 25 and with the following distance based functions:

$$f(d_{ij}) = \begin{cases} \dfrac{1}{d_{ij}} \\ \dfrac{1}{d_{ij}^2} \end{cases}$$

Relative to the first distance based function the second assumes that weights decrease more rapidly as the distance between stations increase. The spatial lag model is estimated using cutoff distances, d^*, of 1, 2, and 3 miles for both distance based functions.

For both the distance based and k-nearest neighbors specifications the weights matrix is normalized so that the sum of the weights, $\sum_j w_{ij}$, equals one. For example, for the $k = 5$ specification $w_{ij} = 0.2$ for firm i's 5 closest neighbors and 0 for all other firms and in the $k = 20$ specification $w_{ij} = 0.05$ for firm i's 20 closest neighbors and 0 for all other firms. As such, the estimate ρ can be interpreted as a firm's response to a 1-unit increase in the average (or weighted average in the case of distance based weights) price of its competitors.

The spatial lag model is estimated by maximum likelihood estimation allowing the log-likelihood to be used as a specification test. Because the weights matrices are based on a priori beliefs about the manner in which strategic interaction may occur, the log-likelihood can be viewed as an indication of which set of weights yields the best fit. Another diagnostic that can test the appropriateness of the weights specification is the Lagrange Multiplier test for spatial error dependence, which tests our assumption that ε_i is independent across locations (i.e. $\eta=0$ in equation 11). A significant result for this test indicates that not all spatial dependence has been eliminated and that the weights matrix is misspecified.

Table 3 shows the spatial interaction coefficient, ρ, from the estimated models along with the log-likelihood and results of the Lagrange Multiplier test. Using the k-nearest neighbors weights appears to be a more appropriate estimation of the underlying model as the log-likelihoods of these estimations are consistently higher than the log-likelihoods of the estimations using inverse distance weights.

TABLE 3–Log-likelihood and Test for Spatial Error Dependence

Weights	ρ (Prob.)	Log-Likelihood	LM Test for Spatial Errors (prob.)
k-nearest neighbors			
k=5	0.479 (0.000)***	1172.5	8.458 (0.004)***
k=10	0.608 (0.000)***	1178.63	3.379 (0.066)*
k=15	0.665 (0.000)***	1176.27	0.339 (0.560)
k=20	0.676 (0.000)***	1165.63	0.023 (0.880)
k=25	0.676 (0.000)***	1158.36	0.028 (0.868)
Inverse Distance			
$W=1/d_{ij}$; d*=1 mile	0.004 (0.402)	1119.66	78.030 (0.000)***
$W=1/d_{ij}$; d*=2 miles	0.004 (0.373)	1119.70	70.739 (0.000)***
$W=1/d_{ij}$; d*=3 miles	0.004 (0.364)	1119.72	66.029 (0.000)***
$W=1/d^2_{ij}$; d*=1 mile	0.037 (0.010)***	1122.61	121.282 (0.000)***
$W=1/d^2_{ij}$; d*=2 miles	0.042 (0.003)***	1123.81	88.773 (0.000)***
$W=1/d^2_{ij}$; d*=1 mile	0.043 (0.002)***	1124.30	76.130 (0.000)***

Notes: p-values in parentheses. Column 1 gives the spatial interaction coefficient measuring the strength of interaction between neighboring stations. Column 3 tests for the presence of spatial dependence in the errors which would indicate that the specification does not fully capture the spatial processes in the data. For the k-nearest neighbors specifications stations are assumed to place equal weight on the prices of its k closest neighbors, whereas for the inverse distance based specifications stations place the greatest weight on its nearest competitors. *indicates significance at the 10% level; **indicates significance at the 5% level; ***indicates significance at the 1% level.

Furthermore, although the estimates of ρ are significant at the 1-percent level when using $W = 1/d_{ij}^2$ weights, the Lagrange Multiplier tests indicate the presence of spatially dependent errors. This suggests that not all of the spatial dependence in the data has been taken into account. The value of ρ is strongly significant in all of the k-nearest neighbors models and, with the exception of $k = 5$, the presence of spatially dependent errors is rejected at the 5-percent level. The log-likelihood takes a value of 1178.63 and 1176.27 for $k = 10$ and $k = 15$, respectively, indicating that these models exhibit the best fit.

The Lagrange Multiplier tests for the absence of spatially dependent errors in these estimations reject the presence of spatially dependent errors. Although the log-likelihood is highest for $k = 10$, the absence of spatially dependent errors can only be rejected at the 10-percent level for this weighting scheme. Of all the models that appear to properly account for all of the spatial dependence in the retail gasoline market, the $k = 15$ model has the highest log-likelihood and therefore is chosen as the appropriate specification. Comparing the estimated spatial interaction coefficient also suggests that the $k = 15$ is the appropriate market area. The coefficient estimate of 0.665 indicates that a firm will increase its price by 6.65¢ in response to its 15 nearest neighbors raising their price by 10¢. The fact that the estimate of ρ does not change dramatically with $k = 20$ and $k = 25$ indicates that a firm's response to its 20 nearest neighbors raising prices is not much different than its response to its 15 nearest neighbors raising prices, which would suggest that firms place little additional weight on the decision of neighbors 16 through 20.

The empirical model is grounded in the assumption that each of the 663 stations is competitors. However, if station owners operate multiple stations within a small geographical area it is reasonable to assume that their pricing behavior will be impacted by their local market power. Although the data includes the named owner for most of the stations, for a large number of observations the station name is recorded instead of the owner name obfuscating matching ownership. For 235 of the 663 observations ownership cannot be definitively determined. Examining the 428 observations for which ownership can be definitively determined, 180 of the stations are owned by an operator of multiple stations. Of the 33 owners operating multiple stations, the average number of stations owned is 5.5, with the largest multi-station owner operating 22 stations. Given the geographic dispersion of these owners' stations multi-station ownership does not appear to be a great concern. Only 40 of the 180 stations have the same owner as one of its 15 nearest competitors. And for 32 of these 40 stations their owner operates only one of its 15 nearest competitors. As for the remaining eight stations whose owners operate more than one of its 15 nearest competitors, four are in a single cluster of stations owned by an operator of thirteen stations and three are in a single cluster of stations owned by an operator of twenty-two stations. In addition, a Moran's I test was performed on dummy variables for each of the 33 multi-station owners. The null hypothesis of the test is that there is no spatial correlation in the location of the owner's stations. For each of the owners the null hypothesis could not be rejected indicating the absence of spatial autocorrelation in the location of their stations. The lowest p-value for the tests is 0.176 for a fourteen station owner and the average p-value is 0.408. As such it appears unlikely that owners of multiple stations are obtaining market power by clustering within a single region.

B. SPATIAL INTERACTION AND DEMAND DETERMINANTS

Although discussion of the results for the entire estimated model is limited to the $k = 15$ weighting scheme, Table 4 shows the estimated model for the $k = 10$, $k = 15$, and $k = 20$ weighting schemes. In the spatial lag model the coefficient estimates of the demand determinants represent the direct, or marginal, effect of a change in a firm's characteristics. The direct effect is magnified as the change has a ripple effect due to the interdependency between firms resulting in a larger total effect on equilibrium prices. Equation (10) demonstrates how the size of the strategic interaction coefficient influences the magnitude of this ripple effect. Following Anselin (2003), $1/(1-\rho)$ is the estimated spatial multiplier of the model which measures the average extent to which the impact of a change in an independent variable is multiplied by the spillovers in the system. In the absence of strategic interaction, $\rho=0$, the demand determinants impact prices solely through the direct effect. As the strength of strategic interaction between stations increases the spatial multiplier increases thereby magnifying the impact that changes in demand determinants have on equilibrium prices. For the 15-nearest neighbor model the strategic interaction coefficient is estimated as 0.665 resulting in a spatial multiplier of 2.985. The magnitude of the spatial multiplier is significant because it indicates that a variable's impact on a station's price comes more from the competitive interaction between stations, as opposed to the direct effect on the station itself.

TABLE 4–Empirical Results

Variable	OLS	*k*=10 Nearest Neighbors	*k*=15 Nearest Neighbors	*k*=20 Nearest Neighbors
ρ		0.60771	0.66535	0.67562
		(0.000)***	(0.000)***	(0.000)***
INCOME	1.36e-07	4.81E-05	6.42E-05	7.12E-05
	(0.050)**	(0.435)	(0.301)	(0.261)
%DRIVE	-0.0009	-0.00041	-0.00042	-0.00042
	(0.001)***	(0.100)	(0.100)*	(0.112)
POPDENS	0.00068	0.00012	-0.00001	-0.00001
	(0.041)**	(0.673)	(0.972)	(0.987)
%CHILD	-0.00057	-0.00020	-0.00015	-0.00017
	(0.000)***	(0.096)*	(0.206)	(0.181)
%MALE	0.0010	0.00078	0.00093	0.00095
	(0.107)	(0.160)	(0.096)*	(0.094)*
CITGO	-0.01198	-0.00922	-0.00968	-0.01112
	(0.130)	(0.189)	(0.171)	(0.123)
CONOCO	-0.02203	-0.01727	-0.01801	-0.01907
	(0.000)***	(0.001)***	(0.001)***	(0.000)***
PHILLIPS66	-0.02982	-0.02898	-0.03012	-0.03094
	(0.000)***	(0.000)***	(0.000)***	(0.000)***
SHELL	-0.00267	-0.00435	-0.00304	-0.00330
	(0.643)	(0.394)	(0.554)	(0.528)
TEXACO	0.00848	0.00927	0.00942	0.00923
	(0.095)**	(0.039)**	(0.037)**	(0.046)**
OTHER	-0.01556	-0.01209	-0.01322	-0.01389
	(0.109)	(0.160)	(0.127)	(0.116)
CONSTANT	1.44231	0.55263	0.46398	0.44875
	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Log-Likelihood		1178.63	1176.27	1165.63
LM Test: χ^2		3.3790	0.3391	0.0229
(Prob.)		(0.066)*	(0.560)	(0.880)

Notes: p-values in parentheses. Specification tests summarized in Table 3 indicate that the specification in column 3 best accounts for the spatial processes present in the data. *indicates significance at the 10% level; **indicates significance at the 5% level; ***indicates significance at the 1% level.

The importance of the large and strongly significant strategic interaction coefficient, and hence the spatial multiplier, is illustrated by examining the impact that the percent of commuters driving to work has on a station's price. The coefficient of *%DRIVE* is -0.00042 and significant at the 10-percent level, indicating that a 10 percentage-point increase in *%DRIVE* has a direct effect of a 0.4¢ decrease in the price of gasoline. However, competition within the interconnected market results in competitors responding to the 0.4¢ shift in the initial firm's reaction function with lower prices of their own which in turn feeds back into the initial firm who responses with further price cuts until the new equilibrium is achieved. Therefore the total effect of a 10 percentage-point increase in *%DRIVE* on a firm's price includes both the direct effect measured by the coefficient of *%DRIVE* and the indirect effect from the feedback of changing prices rippling through the interconnected market. The total effect is calculated by multiplying the direct effect of the coefficient by the spatial multiplier. Consequently, the 10 percentage-point increase in *%DRIVE* ultimately decreases a station's price by 1.2¢, approximately 2/3rds of which results from the geographic competition inherent in the market.

The finding that an increase in the percentage of commuters decreases the pricing power of gas stations is consistent with the expectation that automobile commuters can conveniently purchase gasoline from numerous stations along their regular commutes without incurring increased travel or information costs. The coefficient of *%MALE* is positive and significant at the 10-percent level and indicates that a 10 percentage-point increase in *%MALE* results in a direct effect of a 0.9¢ increase in the station's price and a corresponding total effect of 2.8¢. This finding is consistent with Keyser (2000) who also found a higher demand of gasoline for males versus females. The remaining demand determinants, *INCOME, %CHILD* and *POPDENS* are insignificant indicating that they do not have a direct effect on a stations gas prices.

The brand dummy variables, which proxy for cost differences between brands show strongly significant effects. *CHEVRON* is the excluded category in the regressions. The estimated coefficient for *CONOCO* and *PHILLIPS66* branded stations are negative and significant at the 1-percent level. The estimated direct effect of a *CONOCO* station is -1.8¢ and the estimated direct effect of a *PHILLIPS66* station is -3.0¢. The coefficient for *TEXACO* branded stations is significant at the 5-percent level with an estimate of 0.9¢. The strong significance of brand dummies coupled with the weak significance or lack of significance of the demand determinants is consistent with station prices being driven more by station costs and geographic competition as opposed to local demand. However, since the data lacks station characteristics, such as the presence of a convenience store, fast food outlet or car wash, it could be the case that the significance of brand dummies comes from a brands propensity to offer such valuable services as opposed to variations in the station's wholesale cost of gasoline.

It should be noted that the significance of *%CHILD*, *INCOME* and *%DRIVE* in the OLS model is comparable to previous studies on gasoline pricing. The fact that the estimated coefficients become smaller and less significant is consistent with OLS yielding biased estimates in the presence of unaccounted for spatial dependence. The biased OLS estimates highlight the drawback of ignoring the endogenous nature of the pricing decision in the retail gasoline market.

The finding that gas stations take into account the behavior of nearby stations when making their own pricing decision is crucial to understanding the retail gasoline market. If a highly competitive retail gasoline market prevented local stations from possessing pricing power then variation in local demand would primarily drive variation in prices and we would expect to find little strategic interaction between neighboring stations. The existence of strong strategic interaction suggests that competitive forces at the local level could partially explain the wide dispersion of prices found in the sample. With the gasoline industry having experienced significant consolidation in the late 1990s and early 2000s, the regulatory spotlight has been on the impact of mergers on wholesale gasoline markets. Any regulatory focus on consolidation's impact on retail markets has been limited to preventing a brand from obtaining too large of a market share in a particular area. However, this study's finding of strategic interaction suggests a more complicated competitive environment that simple market share measures do not capture.

VI. Conclusion

Although spatial econometric methods have become the preferred method to test for strategic interaction between governmental jurisdictions, research taking advantage of the methodology's ability to test for strategic interaction between geographically close firms is unjustifiably sparse. The evidence presented here shows two important findings. First that strategic interaction plays an important role in pricing decision of retail gas stations. Consequently, previous research which failed to take such strategic interaction into account may have overestimated the impact of demand determinants on a station prices. Furthermore, the magnitude of the strategic interaction coefficient results in a relatively large spatial multiplier meaning the strong competition between neighboring stations magnifies any change in the market conditions. Second, results indicate that gas stations in this sample take into account the prices of their 15 closest competitors when setting their own price. Specification tests suggest that gas stations places equal weights on the pricing decision of its 15 closest competitors.

In addition to the significant finding of strategic interaction, dummy variables for gasoline brands used as a proxy for cost differences between brands have the most significant impact on retail prices. Retail prices may also be influenced by the percentage of an area's commuters who drive to work. This more mobile population has access to additional low-travel-cost options during their commute resulting in greater local price sensitivity and lower prices. Income and population density do not have a significant impact on local prices and there is weak evidence on the impact of an area's gender mix on prices.

Although the importance of spatial proximity has long been a focus of empirical research in urban economics, spatial econometric methods offer unique insight into the study of all markets which firms compete spatially. This paper reveals a gasoline market more accurately modeled as numerous interconnected submarkets whose interactions resemble overlapping spider webs as opposed to a single market of 663 firms. As such this paper represents an early contribution to what will assuredly be numerous papers examining the more intricate nature of competition between geographically close firms. Although testing the model using more recent prices has a drawback of using demand determinants from the 2000 Census data, it would be interesting to see whether the extensive posting of retail gasoline prices on the internet has lowered the information cost of price comparison enough to offset consumer's travel costs.

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Endnotes

1. Eckert and West (2004) also included a spatial component in their study of Vancouver retail gas prices and found that the existence of a low-priced branded station within 2km has a negative impact on a station's pricing decision. A subsequent study by Eckert and West (2005) found that the presence of a competing station nearby influenced a station's decision to match the market's mode price. The authors use this result to reject the assumption that retail gasoline market was a competitive market in which spatial differentiation did not yield pricing power for firms. Similar to Barron et al (2000, 2004) and Hosken et al (2008) spatial econometrics was not used to control for the resulting endogeneity.
2. The dataset contained average daily prices for regular unleaded gasoline for the second week of February 2001. The number of days in which any particular station had its price recorded varied. For this reason the dependent variable is the average recorded price for the week.
3. Originally automobiles per household and median age were included in the regressions. However, both variables are highly correlated with income.
4. Keyser (2000) found income and percent male to have positive impacts on demand and the presence of children to have an insignificant impact on demand.