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Spatial Variability in Retail Gasoline Pricing Behavior

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Spatial Variability in Retail Gasoline Pricing Behavior

A Thesis submitted in partial satisfaction
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by

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To my parents, Xuezhong Xu and Hua Wang,

To my friends, especially to Tong.

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Abstract

Spatial Variability in Retail Gasoline Pricing Behavior

by

Jing Xu

Retail gasoline prices continue to be of much interest to the public, with significant economic implications. Of course, pricing too has considerable influence on behavioral patterns, particularly travel. Considering the climate and sustainability issues that accompany pricing and consumption of gasoline, the substantive importance of gasoline pricing is of even greater significance. While national and state gasoline prices may vary, they are largely tied to fairly predictable factors, including the price of crude oil, weather, political stability, and refinery production capabilities, among others. However, local and regional gasoline prices can vary considerably. Capabilities for better understanding and predicting variation in gasoline retail prices is both informative and necessary, particularly if spatial factors are considered. This thesis explores characteristics related to gasoline price differences across a region. Of particular interest is assessing price gouging behavior, especially those that unfairly target disadvantaged groups. A spatial analytic framework that incorporates exploratory spatial data analysis, remote sensing, geographic information systems and spatial statistics is proposed to investigate the impact of local market conditions on the retail prices of gasoline across Santa Barbara County, offering important insights on regional price variation.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Few markets have attracted as much public interest and regulatory scrutiny as gasoline retail sales. The retail price of gasoline affects economic conditions, purchasing power, travel patterns, regulations and policies, health, etc. It is therefore a major topic of discussion among economists, lawmakers, and scholars, but also directly impacts everyone operating a motorized vehicle that depends on gasoline. Gasoline is created from the refining of crude oil. It then travels by pipeline, barge, or rail from refineries to distribution terminals. It is lastly transported by trucks to individual gasoline stations. According to the U.S. Energy Information Association (U.S. Energy Information Association, 2011), when purchasing gasoline, there are four components that factored into the final price: 1) crude oil prices, 2) taxes, 3) refining costs and profits, and 4) distribution and marketing costs and profits. Therefore, with the above components changing among spatially differentiated sellers at different times, gasoline prices vary across time and region. While national and state gasoline prices may vary, they are largely tied to the following fairly predictable factors: crude oil costs, weather, political stability, and refinery production capabilities, among others. However, local and regional gasoline prices can vary considerably.

Although price variation does exist within a local market, most stations charge consumers reasonable prices for gasoline. However, unfair gasoline pricing practices, including charging too much or too little, are not unusual. The main interest of this thesis is in exploring these abnormal practices. Termed price gouging, increasing the gasoline retail price to an unreasonable amount is subject to stringent government scrutiny. Gasoline price gouging can be triggered by excessive demand following crises like hurricanes and floods. The Federal Price Gouging Prevention Act (H.R.2070), which was introduced by the U.S. House of Representatives in May, 2013, though it was not passed, defined price gouging as setting a price that is either "unconscionably excessive" or that "indicates the seller is taking unfair advantage of the circumstances of the crisis to increase prices unreasonably."[1] Although price gouging is usually thought of as the excessive price increase triggered by an emergency or disaster, price gouging also occurs without a disaster. Some states, Michigan and Maine for example, do not require emergencies/disasters but rather simply have general prohibitions on excessive price increases or profits.[2]

While some law and economics scholars argue that price gouging is merely a practice to maintain market equilibrium and objective price controls (Rapp, 2006; Zwolinski,

[1] A similar definition of price gouging can be found in The Federal Price Gouging Prevention Act (H.R.1252), which was passed by the U.S. House in May, 2007, but killed in the Senate.

[2] In Michigan, the UDAP Statute MCL 445.903(1)(z) is not specifically targeted at disaster-triggered gouging. Instead, it prohibits charging a price in gross excess of the price for which similar products or services are sold. Likewise, in Maine, 10 M.R.S.A. § 1105 (profiteering) 5 MRSA § 207 (UTPA) forbids unjust or unreasonable profits in the sale, exchange or handling of necessities.

2009), price gouging is generally thought to be detrimental to consumers. Certain consumer groups, however, are more susceptible to price gouging. The most common victims of price gouging are people with low incomes. An exceptionally high price directly limits their ability to purchase gasoline, undermining access to transportation including driving a car and using mass transit. Due to increased transport costs, low-income groups would be forced to make further tradeoffs on travel, education, work, health, nutrition, etc. Moreover, for people living on a tight budget, gasoline price increases will result in a considerable reduction in other expenditures. Consequently, gasoline price gouging will lead to social inequity by hindering equitable access to necessities and limiting opportunities for the poor/disadvantaged, important aspects of social sustainability (Yiftachel and Hedgcock, 1993; Vojnovic, 2014).

Price gouging can occur at a station when gasoline inventories are depleting at a faster pace than usual, or rather demand exceeds supply. Facing this imbalance, stations are likely to increase prices to make more profits and slow demand. An emergency or disaster would usually contribute to an imbalance between supply and demand out of the necessity. However, gasoline price gouging also exists in the retail market where there are no sudden demand hikes or concerns about supply. Reasons for the occurrence of non-emergency/non-disaster triggered price gouging in the retail gasoline market might include: premium pricing strategies, low market competition, spatial advantages and others. Of particular interest in this thesis is spatial advantage of gas stations, such as easy access and close proximity to popular locations. Accordingly, stations might target certain consumer groups and earn enough sales to keep themselves in business even though they charge unreasonably high prices. Exploring how the location of gasoline stations may contribute to the occurrence of price gouging is therefore important for understanding regional gasoline price variation.

The purpose of this thesis is twofold. First, exploration of significant determinants of local gasoline retail price differentials and the roles they play in the retail market is undertaken. Second, there is interest in detecting everyday price gouging practices, seeking to explain the underlying motives behind unusual pricing behavior. To these ends, a spatial analytic framework that incorporates exploratory spatial data analysis (ESDA), remote sensing, geographic information systems (GIS), and spatial statistics is proposed. An empirical study focused on the gasoline retail market in the Santa Barbara County is undertaken, shedding light on gasoline price variation and potential price gouging practices in the region.

Chapter 2

Background

Many longitudinal and cross sectional studies on gasoline price variation have been conducted. Studying how retail gasoline prices react to shocks in the price of crude oil as well as wholesale rates is often a focus (Cabral and Fishman, 2012; Lewis, 2009; Tappata, 2009; Verlinda, 2008; Yang and Ye, 2008). Another important area of study in gasoline price dynamics is the Edgeworth cycle, having to do with quick rises in prices over days, followed by slow decline to the original price over several weeks (Castanias and Johnson, 1993). A number of studies have sought to detect or prove the presence of the Edgeworth cycle (Castanias and Johnson, 1993; Doyle and Samphantharak, 2008; Eckert, 2013; Noel, 2007; Wang, 2008; Zimmerman et al., 2011).

In addition to studies on gasoline price dynamics over time, considerable research has been done on the determinants of price levels and how prices change across markets and stations. Some researchers used reduced form equations to study how market structure affects gasoline prices. For instance, crude oil prices were found to be important in determining wholesale prices, and wholesale prices were shown to be the primary factors for gasoline retail prices (Chouinard and Perloff, 2007; Sen, 2003). Other work has studied the role of specific events on prices, including the public announcement of antitrust investigations, the implementation of price floor regulation, the enactment of gas station divorcement law, etc. (Barron and Umberck, 1984; Carranza et al., 2012; Erutku and Hildebrand, 2010).

Attention to cross sectional price variation at the station level is of primary interest in this thesis. Several empirical studies utilized regression analysis to identify the most significant variables associated with price differentials among sellers. Price control variables can include local demographics and station location, physical station characteristics, brand and contractual arrangements, station density, and local concentration, although significant explanatory variables vary in different studies (Eckert, 2013). For example, the relationship between the number of sellers (seller density) and either the average price or price variance was investigated by using station-level gasoline price data in the metropolitan areas of Phoenix, Tucson, San Diego, and San Francisco (Barron et al., 2004). Results indicated that a higher number of stations within a geographic market was associated with both a lower average price and a lower level of price dispersion. Similar empirical studies exploring how different characteristics affect gasoline prices were performed, although with different foci: some were interested in how market concentration was related to station density (Clemenz and Gugler, 2006); some presented the asymmetry of market competition along commuter routes (Cooper and Jones, 2007); and some investigated the role of demand-side predictors in explaining gasoline prices

(Ning and Haining, 2003). These studies used regression models to explain existing gasoline pricing practices. However, no work has focused on exploring spatial factors and abnormal pricing behavior in the gasoline retail market such as price gouging.

Although studies on price gouging have explored abnormal pricing behavior, most have focused on the rationality and influence of price gouging and anti-gouging statutes (Rapp, 2006; Snyder, 2009; Zwolinski, 2009). Some researchers hold that price gouging prevents equitable access to essential goods (Snyder, 2009) and that anti-gouging laws may offset market inefficiencies caused by the decision-making heuristics of suppliers (Rapp, 2006). While others argue that price gouging is morally acceptable behavior and that laws prohibiting price gouging are not morally justified (Zwolinski, 2009). One study compared empirical model coefficients to identify evidence of gasoline price gouging when Hurricane Rita attacked Texas (Neilson, 2009). But like other studies on price gouging, this work simultaneously examined price gouging and the event that triggered the price gouging during the hurricane. No previous studies have attempted to understand price gouging outside of emergencies/disasters in order to explore the causal and spatial factors behind it.

Chapter 3

Study Area and Data

This study investigates the impact of local market conditions on the retail price of gasoline across the County of Santa Barbara, a market characterized by higher average prices compared to both the United States and California. Santa Barbara County is located in the southern portion of California, approximately 100 miles north of Los Angeles. The total area of this region is 3,789 square miles (of which 2,735 square miles are land), with a total population approaching 450,000 (U.S. Census Bureau, 2016). People with Hispanic or Latino origins account for 44.1%, with lower proportions of high school education and even lower rates of university education. In addition, about 13% of households in the county are regarded as living in poverty, making them particularly vulnerable to gasoline price gouging. The population is most concentrated in the southern coastal plain. The U.S. Route 101, and State Routes 144, 154, and 166 serve as primary transportation linkages in the region. Economic activities including education, engineering, agriculture, resource extraction (particularly petroleum and diatomaceous earth) and winemaking, but also tourism (County of Santa Barbara, 2017).

Daily gasoline prices at 108 stations in Santa Barbara County from May 1, 2015 to May 12, 2016 were acquired from GasBuddy. This data is a product of volunteered geographic information (VGI), which uses mobile devices and the internet to create, assemble, and disseminate geographic information provided by individuals voluntarily (Goodchild, 2007). Our analysis focuses on retail prices of regular gasoline. Other information, such as gasoline brand, spatial location, and the time when the price was collected, is also available in the data provided by *GasBuddy*.

Station characteristics, such as the number of gasoline pumps/fueling positions available, the presence of an onsite convenience store, the option of a car wash service, mechanical service, and whether or not a station offers full service, were collected through field survey by the authors. Such services may have some impacts on pricing behavior.

The local area surrounding a station may also influence pricing behavior. Accordingly, information was obtained on socio-economic characteristics of the region. The 318 block groups in Santa Barbara County (excluding the Channel Islands) were acquired from the U.S. Census. Associated attributes included the total number of households, the total number of households below poverty level, and the population driving to work. Land use data is also important, such as shopping centers and schools. For each of the 130,208 parcels in Santa Barbara County, the specific land use type was acquired from the Santa Barbara County Assessor.

Transportation conditions are considered in this study as well: publically available shapefile data was obtained from the U.S. Census for primary and secondary roads in

Santa Barbara County, as well as traffic counts at 123 major intersections between highways and local arterials in the county from the California Department of Transportation. Satellite images with resolution of about 50 inches (2016) have also been obtained from Google Maps to assist in the analysis.

Chapter 4

Methods

Assessment of gasoline price variation by station is the primary interest of this research. Two goals are to identify factors associated with gasoline price differentials in the region and to detect instances of price gouging behavior. Thus, a spatial analytic framework that incorporates ESDA, remote sensing, GIS, and spatial statistics is proposed (Figure 4.1). This methodological framework reflects a scientific and systematic structure to facilitate assessment of gasoline prices, relying on a variety of approaches to acquire, manage, manipulate, analyze, and display associated geographic data.

4.1 ESDA (Exploratory spatial data analysis)

One component of the proposed analytical framework in Figure 4.1 is ESDA. It often focuses on the distinguishing characteristics of geographic data, spatial autocorrelation and spatial heterogeneity (Anselin, 1998). ESDA is utilized in a number of ways in this research to derive pricing behavior representations, analyze prices and process gasoline

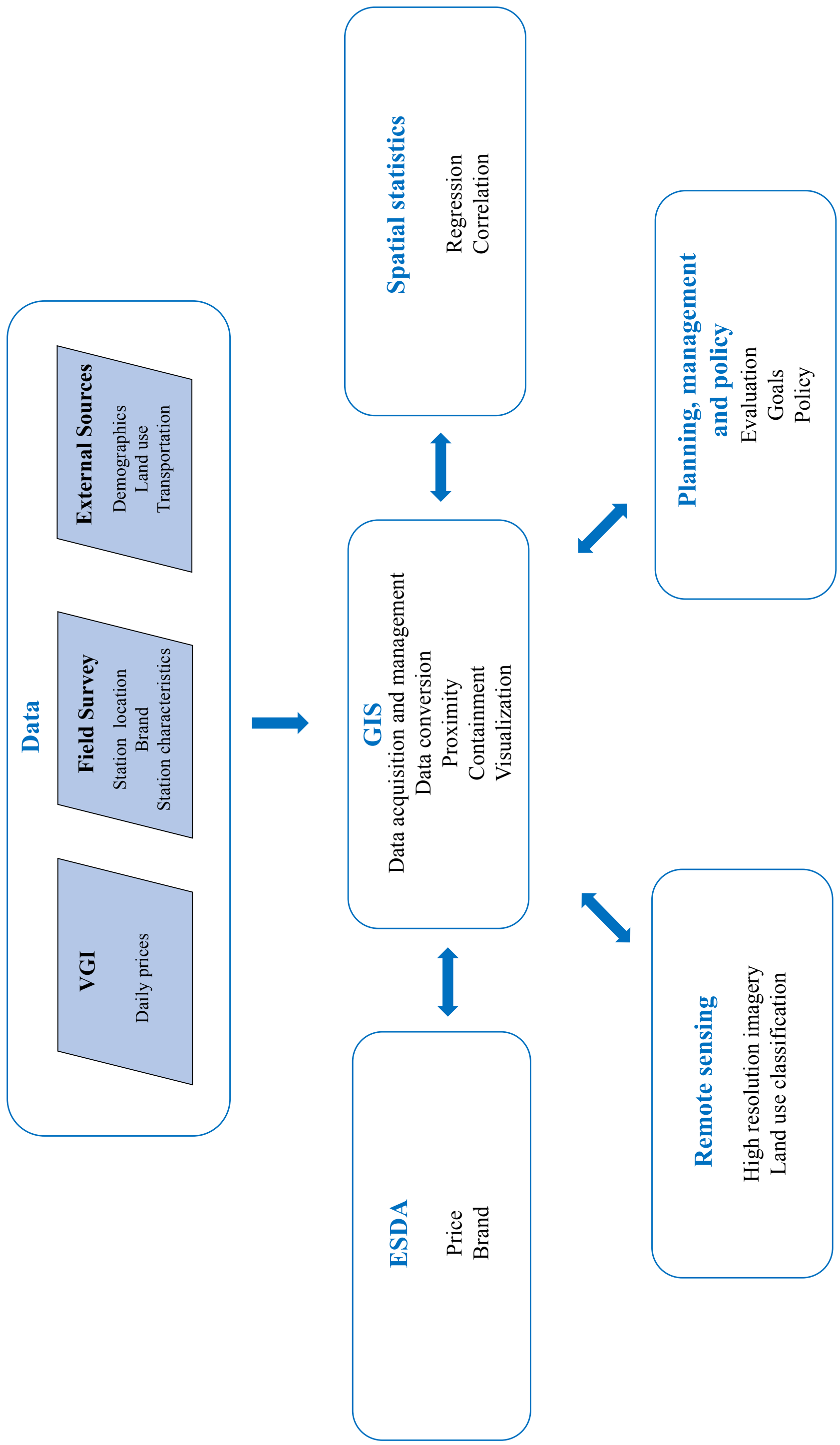

Figure 4.1 Methodological framework

brand information in preparation for further analysis. Since daily prices were collected through VGI, there is no guarantee of quality or accuracy. To deal with this, as well as missing data, average reported price for a short period of time was used for each station. Specifically, we sought an optimal period with the least amount of missing data and lowest price variability. This process can be viewed as a bi-objective optimization problem. To formalized the approach, notation is introduced:

p = index of periods

i = index of stations

γ = weight

$$N_{ip} = \begin{cases} 1 & \text{if station } i \text{ has no reported daily price in period } p \\ 0 & \text{if station } i \text{ has at least one reported daily price in period } p \end{cases}$$

σ^2_{ip} = price variance for station i in period p

This optimization problem aims to find a period p which minimizes the following:

$$\min_p \{\gamma \sum_i N_{ip} + (1-\gamma) \max_i \sigma^2_{ip}\} \tag{4.1}$$

The first component, $\sum_i N_{ip}$, represents the number of stations without price data during period p. The second part, $\max_i \sigma^2_{ip}$, accounts for station price variance during period p. The weight, γ, allows for importance scaling given different measurement units. Constraints can be imposed on this problem, such as consecutiveness of selected days and the length of periods. Given the best evaluation period, average price for each station,

$PRICE$, is computed to represent its pricing behavior in that period. Then, numeric and graphical analysis can be conducted based on derived price representations.

Gasoline brand is hypothesized to play an important role in pricing, so another important aspect of ESDA is incorporating gasoline brand information into the analysis. Given that brand information is a nominal data type, it is converted into an ordinal value in order to be quantitatively analyzed. Often, major oil companies set higher retail prices and stations must therefore price higher as a result. From the consumer perspective, gasoline quality also varies by brand (Barron et al., 2004). Therefore, a binary variable, $MAJOR$ is generated to indicate a major brand. This is a classification problem based on average prices, number of stations, market proportions, gasoline quality, suppliers, spatial distributions of brands, etc.

4.2 Remote sensing

A second analytical method in Figure 4.1 is remote sensing, the practice of deriving information from Earths land and water surfaces through the detection of electromagnetic radiation levels using overhead sensors (Campbell and Wynne, 2011). Remote sensing can be utilized to generate descriptors for land use and/or socioeconomic conditions when onsite observation is not possible. The estimates of local conditions around stations based on remote sensing images provide independent variables for regional gasoline prices in regression analysis.

Using remote sensing, it is possible to derive attributes characterizing local conditions around station i as:

$$a_i = f(\lambda_1, \lambda_2, \lambda_3, \cdots) \tag{4.2}$$

where a_i represents an attribute of a defined area around station i, $f()$ is a function and $\lambda_1, \lambda_2, \lambda_3, \cdots$ are the detected radiation for different wavelength ranges. In the context of gasoline price variation, a_i might represent the land use surrounding station i, such as amount of impervious surface, vegetation and/or water, or socioeconomic descriptors like population, income level, and number of establishments. To obtain such estimates, the function is structured as a recognition process. Often regression analysis is used along with high resolution images to account for local streets, neighboring districts, and other information. Collectively, remote sensing is important for better understanding the surrounding environment with respect to specific local pricing behavior.

4.3 GIS (Geographic information systems)

A third supporting method shown in Figure 4.1 is GIS, the combination of hardware, software, and procedures that support the acquisition, management, manipulation, analysis, and display of spatially referenced information (Church and Murray, 2009). In the context of exploring gasoline price variation, GIS provides important spatial analytic capabilities, including spatial data processing, data conversion, proximity measurement, containment analysis, and visualization.

The assessment of proximity involves qualifying spatial relationships between objects and/or physical geographic features. Proximity refers to distance as well as topological relationships, such as adjacency, contiguity, intersection, and connectivity (Church and Murray, 2009). Station proximity to its competitors, shopping centers, schools, and main roads is all potentially important for exploring pricing. Derivation of proximity could be based on network, Euclidean or rectilinear distance, or travel time. If d_{ik} represents the distance from station i to object k, then it is possibly to characterize proximity relationships, assuming object k is another station, school, shopping center, road, etc. Proximity analysis is also used to specify neighbor relationships such as those used in spatial autocorrelation and spatial regression. For example, this may be accomplished as follows:

$$w_{ii'} = \begin{cases} \frac{1}{\sum_{i'} w_{ii'}} & \text{if } d_{ii'} \leq T_d \\ 0 & \text{if } d_{ii'} > T_d \end{cases}$$

where $w_{ii'}$ is the spatial weight, denoting whether or not station i' is a neighbor of station i, $d_{ii'}$ is the distance between stations, and T_d is a distance threshold.

Containment is another GIS based technique to relate various spatial objects by determining whether one object is completely within another object or an area. The numbers/densities of stations, shopping centers, schools and demographic attributes around stations might affect gasoline prices. They can be calculated based on the application of containment. If C_{ik} is 1 when object k falls into the boundary of station i, or their boundaries intersect, and C_{ik} is 0 otherwise, then $\sum_k C_{ik}$ represents the number of objects around station i. Object k can be other station, shopping center, school, etc.

4.4 Spatial statistics

A final component of the analytical framework in Figure 4.1 is spatial statistics. A prominent use of spatial statistics is for estimating the relationship between independent variables and gasoline prices. A linear regression model for explaining station pricing behavior is as follows:

$$Y = \sum_j \beta_j X_j + \epsilon \tag{4.3}$$

where Y is the gasoline price, that is $PRICE$. X_j represents independent variable j for each observation, such as $MAJOR$, surrounding station density, distance to its nearest school, etc. ϵ is the error term, assumed to be independent and identically distributed. β_js represent coefficients to be estimated.

Considering the existence of potential spatial dependencies, spatial lag and error regression models are also considered. The spatial lag model is formalized as:

$$Y = \rho WY + \sum_j \beta_j X_j + \epsilon \tag{4.4}$$

The spatial error model is:

$$Y = \sum_j \beta_j X_j + rWE + \Xi \tag{4.5}$$

W is spatial weights matrix containing $w_{ii'}$, derived using proximity analysis. E is the original error term vector. Ξ is a new random error term. ρ and r are additional parameters to be estimated.

Statistical tests and residual plots are used to investigate whether or not there are diagnostic problems. High leverage points and outliers are detected to assist in identifying abnormal independent variables and pricing behavior. In particular, outliers are used to indicate potential price gouging behavior. Station i is identified as an outlier if the absolute value of its deletion residual e_i^* is larger than the threshold T_e.

Based on regression results, associated analytics are used to explore likely gasoline price gouging practices. Station i is regarded as a price gouger if the following two conditions are observed:

A. $|e_i^*| \leq T_e$

B. $\frac{Y_i - \bar{Y'}}{\bar{Y'}} \geq \tau\%$, where $\bar{Y'}$ is the average price excluding station i

Condition A suggests station i is an outlier. Condition B establishes whether the observed price at station i is significantly high. Parameters T_e and τ can vary in different application contents. Collectively, satisfying both conditions A and B suggests that a station engages in abnormally high pricing behavior.

Chapter 5

Results

An optimal two-week period ($p = 14$ and $\gamma = 0.5$), with the least amount of missing daily prices and the least price variation, was found to be April 27, 2016-May 10, 2016. During this period, more than 90% of stations have price information collected for more than 10 days with price variance of 0.139. Only three stations have no data for one or more days.

There are 19 known gasoline brands and 13 stations selling unbranded gasoline (Table 5.1). Considering number of stations, proportions, average prices and also popularity of different brands, Mobil, Chevron, 76 and Shell are classified as major brands. They are all well-known gasoline brands nationally and have a large number of stations in the region, constituting 44.4% of the county's gasoline market. They are also spread across the region. Although ARCO and USA Gasoline are popular and possibly supplied by Andeavor (previously known as Tesoro), as are the above identified major brands, they are not classified as major brands. The analysis and modeling do not find ARCO and USA Gasoline to be major brands. This is no doubt due to the pricing behavior

Table 5.1 Gasoline brands

Brand	Average Price ($/gallon)	Number of Stations	Proportion(%)
Mobil	3.189	11	10.476
Chevron	3.110	16	15.238
76	2.908	14	13.333
McCormix	2.905	3	2.857
Shell	2.881	7	6.667
Spirit	2.795	1	0.952
Alliance	2.759	1	0.952
7-Eleven	2.747	3	2.857
Vons	2.726	1	0.952
Fuel Depot	2.725	5	4.762
Valero	2.718	6	5.714
Fastrip	2.699	1	0.952
Gasco	2.688	2	1.905
Conserv Fuel	2.684	5	4.762
World Oil	2.662	1	0.952
USA Gasoline	2.660	8	7.619
ARCO	2.637	5	4.762
Circle K	2.590	1	0.952
Food4Less	2.562	1	0.952
Unbranded	2.835	13	12.381

as they both operate as discounting retailers. Analysis specifying exploring ARCO and USA Gasoline as major brands found they are not significantly different from non-major brands statistically, with regression results similar to those in column 3 of Table 5.3. Thus, Mobil, Chevron, 76 and Shell are regarded as major brands and others are non-major brands.

The descriptive statistics of independent and dependent variables are given in Table 5.2, along with variable definitions. The variability in gasoline prices and household densities is given in Figure 5.1. An obvious spatial pattern is that gas stations are

Table 5.2 Descriptive statistics of variables

	Variables	Min	Max	Median	Mean	Standard Deviation
$GAS250$	Number of stations within 2.5 miles around a station	0	23	11	11.35	5.994
$NGASDIST$	Distance to a nearest station (mile)	0.031	31.862	0.176	0.201	3.121
$NMINORDIST$	Distance to a nearest station selling non-major brand gasoline (mile)	0.031	32.900	0.359	1.113	3.429
$MINORIN5$	Number of stations selling non-major brand gasoline among the nearest 5 stations	0	5	3	2.933	1.235
$STORE$	Whether or not there is a store	0	1	1	0.886	0.320
$CARWASH$	Whether or not a carwash service is provided	0	1	0	0.219	0.416
$AUTOMOTIVE$	Whether or not an automotive service is provided	0	1	0	0.181	0.387
$FULLSERVICE$	Whether or not a full service is provided	0	1	0	0.019	0.387
$FUELINGPOS$	The number of fueling positions	2	16	8	8.362	2.853
$HH175$	Household density within 1.75 miles around a station (household/mile^2)	0.741	2475.80	358.771	452.5	512.077
$POVERTY275$	Ratio of household in poverty within 1.75 miles around a station	0.061	0.302	0.114	0.132	0.049
$DRIVING2$	Ratio of population driving to work within 2 miles around a station	0.272	0.416	0.389	0.377	0.029
$SHOP275$	Number of shopping centers within 2.75 miles around a station	0	44	19	18.66	12.154
$NSHOPDIST$	Distance to a nearest shopping center (mile)	0	31.860	0.176	0.822	3.341
$SCH025$	Number of schools within 0.25 miles around a station	0	5	0	0.524	0.822
$NSCHDIST$	Distance to a nearest school (mile)	0.007	1.502	0.297	0.333	0.236
$NROADDIST$	Distance to a nearest primary or secondary road (mile)	0.002	0.144	0.054	0.144	0.215
$MAJOR$	Whether or not a station sells major-brand gasoline	0	1	0	0.457	0.501
$PRICE$	A station's average price in the selected period ($/gallon)	2.558	4.799	2.779	2.872	0.305

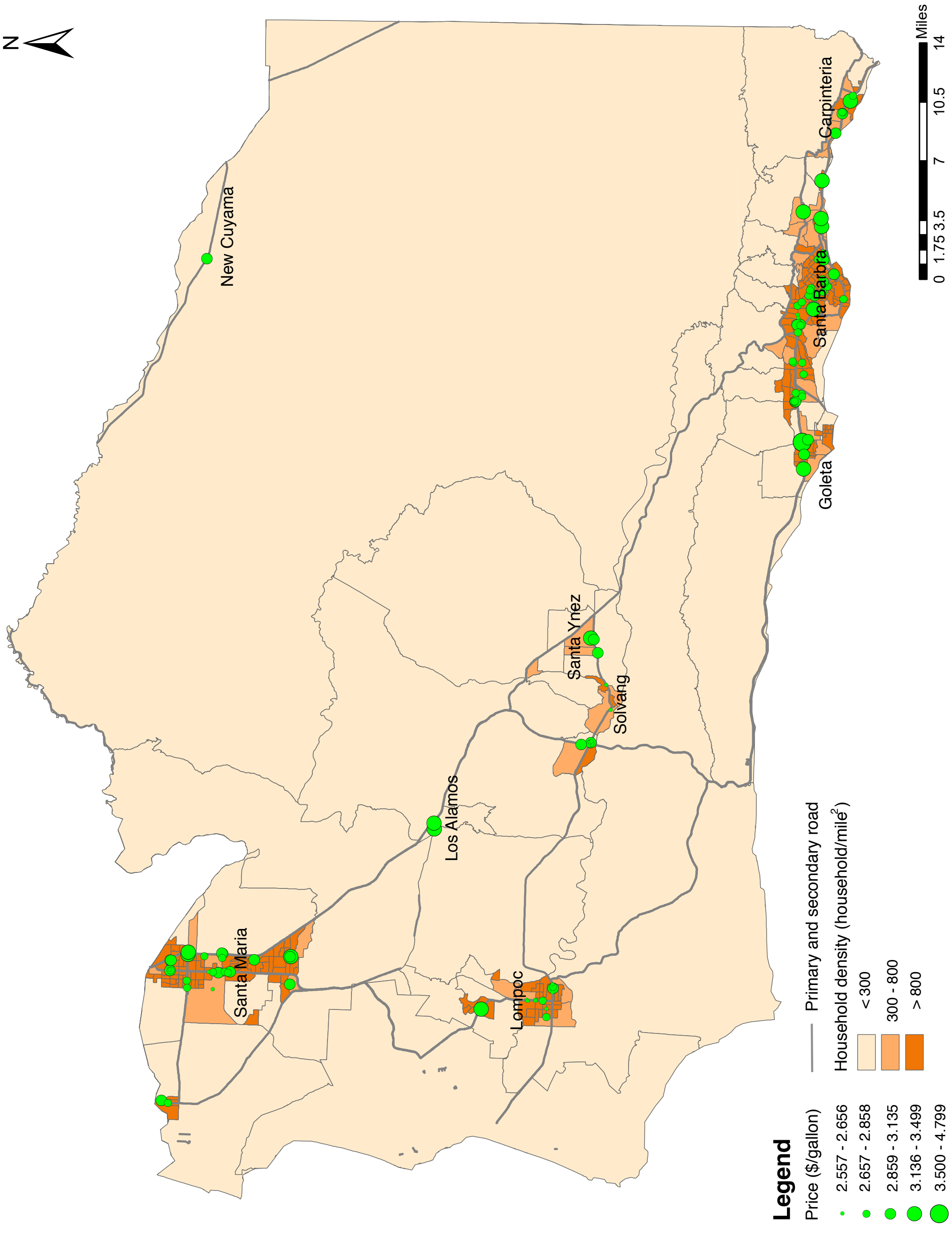

Figure 5.1 Stations in the study region

clustered along with population and economic activities, with Santa Barbara, including adjacent cities of Goleta and Carpinteria, Santa Maria, Solvang and Lompoc serving as primary concentrations. A station has around 11 neighboring stations on average located within 2.5 miles. The average distance between a station and its nearest competitor is about 0.201 miles, with a median of 0.176 miles. The high station densities and low distances between stations also reflect the spatial clustering of stations. A gas station has on average 453 households per square mile surrounding it within 2.75 miles, 19 shopping centers within 2.75 miles and 0.524 schools within 0.25 miles, confirming the observation that stations are located near activity centers. Most stations are positioned along primary and secondary roads as well, with close proximity to traffic arteries and indicating convenient access. The average gasoline price in the county was \$2.872/gallon and the highest price was \$4.799/gallon. It is worth noting that gasoline prices were relatively lower in urban areas with high station density compared to rural areas or those near the urban fringe.

Regression results are summarized in Table 5.3. The initial model used independent variables consisting of station density ($GAS250$), proximity to other stations ($NGASDIST$), station characteristics ($STORE$, $CARWASH$, $AUTOMOTIVE$, $FULLSERVICE$ and $FUELINGPOS$) and demographics around stations ($HH175$, $POVERTY275$ and $DRIVING2$). The best fit model is indicated in column 1 of Table 3. The model only explains about 17% of the price variation ($R^2 = 0.170$) with $GAS250$ and $DRIVING2$ being statistically significant. Spatial factors, including densities of nearby activity centers ($SHOP275$ and $SCH025$) and proximity to activity centers and main roads ($NSHOPDIST$, $NSCHDIST$ and $NROADDIST$), are then considered. The best fit model in this case is indicated in column 2 of Table 5.3. This model increases explanatory power slightly, giving an R^2 of 0.219. Brand information ($MAJOR$, $NMINORDIST$ and $MINORIN5$) is then considered (column 3 in Table 5.3), which dramatically improves R^2 to 0.668. A range of diagnostics was undertaken, including the evaluation of error terms, assessment of multicollinearity and examination of spatial dependency. No significant issues were found.

The negative relationship between price ($PRICE$) and station density ($GAS250$) is significant both economically (2.8 cents per gallon) and statistically (99% confidence level). More competitors around a station contributes to lower prices. It is interesting to find that the distance to the nearest station also negatively affects price. The offer of a car wash service ($CARWASH$) can reduce price by around 15 cents per gallon, while providing an automotive service ($AUTOMOTIVE$) increases price by about 10 cents per gallon. Household density within 1.75 miles ($HH175$) negatively influences price significantly, although at a small magnitude. Increases in percentage of household below poverty and population driving to work ($POVERTY275$ and $DRIVING2$) decrease prices by 2 and 5.5 cents per gallon, respectively. With denser shopping centers ($SHOP275$) and schools ($SCH025$), gas prices are higher. However, the smaller a stations distance to a shopping center ($NSHOPDIST$), the lower the price. The fact that gasoline stations owned by supermarkets usually charge lower prices to earn business sup-

Table 5.3 Regression results

	Dependent Variable: $PRICE$		
	1	2	3
$GAS250$	0.014***	−0.011**	−0.028***
$NGASDIST$		−0.051**	−0.051***
$STORE$			
$CARWASH$			−0.150***
$AUTOMOTIVE$			0.103**
$FULLSERVICE$			
$FUELINGPOS$			
$HH175$			0.0002***
$POVERTY275$			−1.945***
$DRIVING2$	−2.667***	−2.999***	−5.458***
$SHOP275$			0.013***
$NSHOPDIST$		0.050**	0.056***
$SCH025$			0.067***
$NSCHDIST$			
$NROADDIST$			−0.306***
$NMINORDIST$			
$MINORIN5$			−0.083***
$MAJOR$			0.319***
Intercept			5.27***
Obesrvations	105	105	105
R^2	0.170	0.219	0.668
Adjusted R^2	0.154	0.188	0.620
Residual Std. Error	0.281 (df=102)	0.275 (df=100)	0.188 (df=91)
F Statistic	10.437*** (df=2; 102)	7.004*** (df=4; 100)	14.057*** (df=13; 91)

Notes: ** p-value is less than 0.05, *** p-value is less than 0.01, df: degree of freedom.

ports such a positive correlation. The relationship between $PRICE$ and $NROADDIST$ is significantly negative: stations located near main roads set higher prices, likely due to convenient access. Stations representing major brands ($MAJOR$) have prices around 32 cents per gallon higher. The number of surrounding minor-brand stations ($NMINOR5$) is an important predictor as well, showing significantly negative correlation with gasoline price. With a high proportion of minor-brand stations as the nearest five stations, this might generate competition that serves to pulls down prices.

Stations 22, 30, 98 are tested as high leverage observations (having extreme independent variables) with values more than 3 times as large as the mean leverage. Stations 22 and 30 are located near the intersection of U.S. Route 101 and State Route 135 (Figure 5.2). They have no other nearby competitors and no shopping centers within 10 miles. Gasoline was priced 50 cents per gallon higher than the regional average. Station 98 is located in a sparsely populated area near State Route 166, with no stations and no shopping centers within 31 miles (Figure 5.2). It is sandwiched by Los Padres National Forest in the south and mountain ranges in the north. As the only gasoline station along State Route 166 within the county, it charged $2.999 per gallon, 14 cents higher than the average. The observed isolated environments imply that these stations have quite different characteristics from most stations that cluster in urban areas, leading to the detected high leverage values. Areas with little competition likely explain observed higher prices.

Table 5.4 Conditions for Stations 35, 42 and 82

Station ID	Deletion Residuals	$\frac{Y-\bar{Y'}}{\bar{Y'}}$
35	3.113	15.0%
42	2.129	22.1%
82	9.552	68.2%

Stations 35, 42, 51 and 82 are detected as outliers with their deletion residuals larger than 2 (in absolute value), among which only Station 51 has a negative residual. The

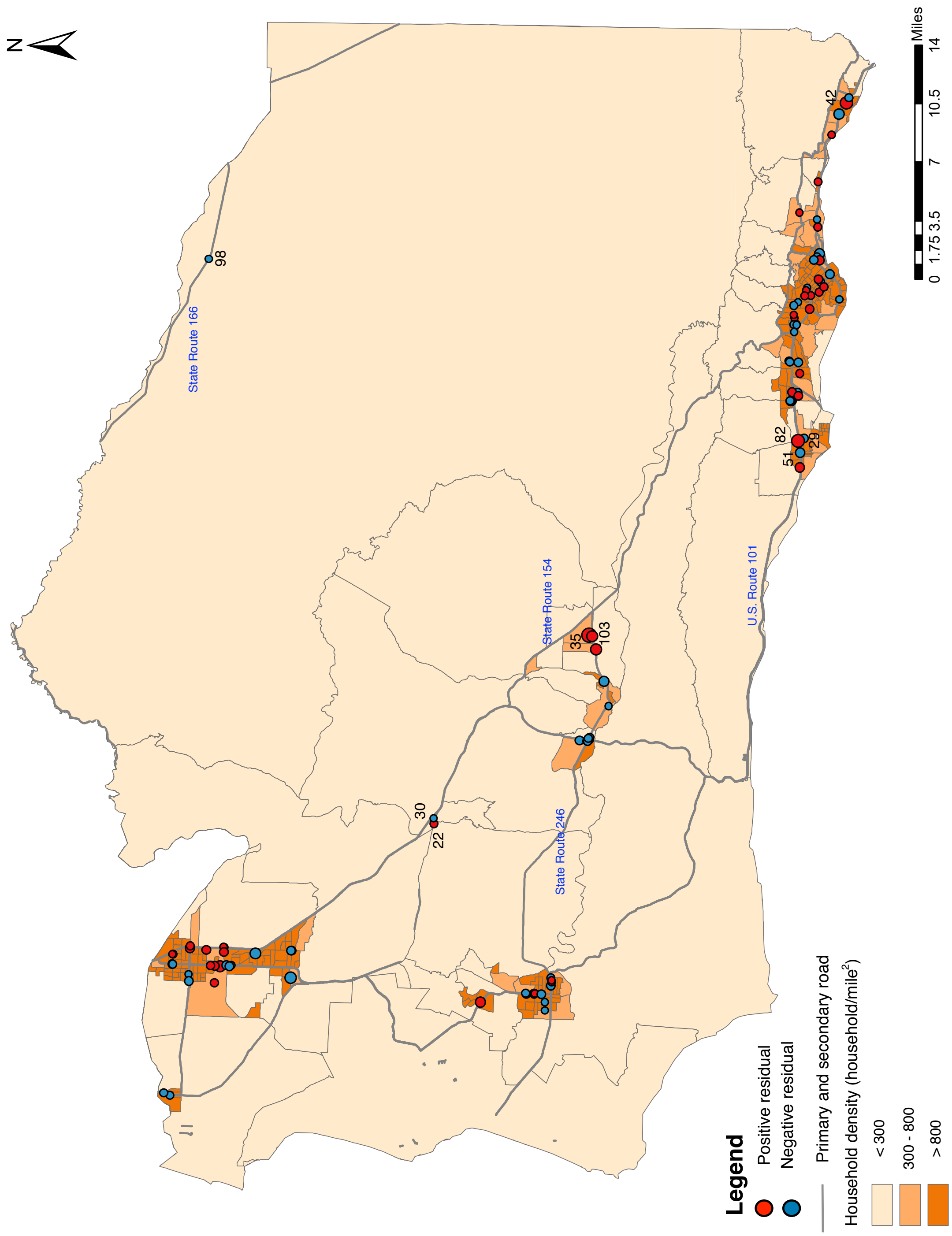

Figure 5.2 Residuals for gas stations

residuals are shown in Figure 3, with large dots denoting large absolute values of residuals. Stations 35, 51 and 82 have price data collected every day from April 27 to May 10, 2016 and there is only one missing price for Station 42 on May 7, 2016. No obvious price fluctuation for these four stations is observed. Therefore, the average prices of these stations during the evaluation period reflects reported pricing behavior. The model is also fitted without these observations. No significance difference in model fit or estimated variable coefficient values was found (column 3 in Table 5.3). Based on conditions A and B ($T_e = 2$ and $\tau = 15$), Stations 35, 42 and 82 are found to engage in price gouging behavior, as summarized in Table 5.4.

Chapter 6

Discussion

One likely reason for price gouging behavior is that a station targets certain groups in need of fuel without alternative options, or for whom it is most convenient to purchase gasoline based on location. A station can earn enough sales to stay in business using such a pricing strategy even though it charges consumers a significantly higher price than average. The detected price gouging behavior of Station 82 (Mobile), for example, selling gasoline for about \$2 per gallon higher than average, is regarded as a prime example of targeting specific groups. Station 82 is located right off the U.S. Route 101 exit at Storke Road/Glen Annie Road, attracting drivers from three arterial roads (Figure 6.1). On the one hand, Station 82 is likely to target long-trip drivers leaving the urban area via U.S. Route 101 north (appears to be west in direction for area shown in Figure 6.1) or entering the urban area via U.S. Route 101 south (appears to be east in direction for area shown in Figure 6.1). As the principal route connecting the region, large traffic volumes along U.S. Route 101 can be observed. If people are heading north on U.S. Route 101, the location of Station 82 enables it to essentially be the last gas station before getting to

Solvang. Figure 6.2 depicts the situation and is communicated through two signs. The first conveys that the next rest stop is 23 miles ahead. The next sign indicates gasoline availability at the next exit, Storke Road/Glen Annie Road. Conversely, its location represents the first opportunity for fuel upon entry to the Goleta/Santa Barbara region traveling south.

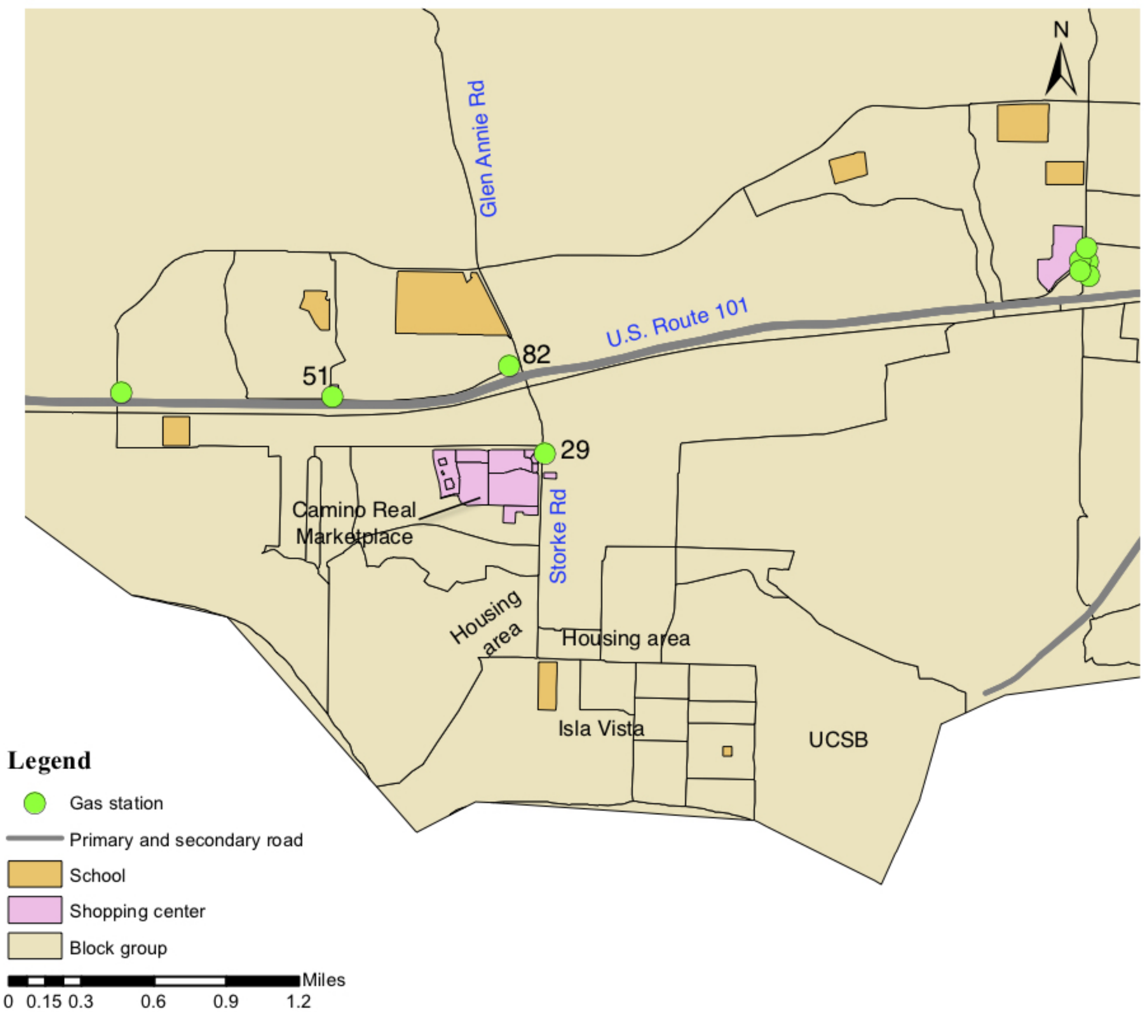

Figure 6.1 Local conditions around Station 82

Figure 6.2 Traffic signs before exit 108 (Storke Road/Glen Annie Road) of northbound U.S. Route 101

On the other hand, Station 82 also targets people who drive on Storke Road/Glen Annie Road to access local activity centers. Glen Annie Road connects Dos Pueblos High School and a golf course from U.S. Route 101. More importantly, Storke Road provides the most direct access to two major destinations, Camino Real Marketplace and Isla Vista, from U.S. Route 101. Camino Real Marketplace is one of the busiest shopping centers with the only Costco and Home Depot in the southern coastal region of the county. Further to the south along Storke Road are Isla Vista, UCSB Campus housing, and a concentration of apartments and residential housing, with a significant population of local residents, students and visitors. The immediate proximity to these two activity centers leads to large traffic volumes passing near Station 82, especially from U.S. Route 101 along Storke Road. The annual average daily traffic count of Storke Road from U.S. Route 101 is 65,600 vehicles per year, almost twice the average intersection traffic of 30,939 vehicles per year in the county. Although Station 29 also has close proximity to this area, Station 82 is the first station for people heading to these activity hotspots when getting off U.S. Route 101. Therefore, Station 82 has a significant locational advantage, enabling a strategy of price gouging behavior on a daily basis.

Station 82's abnormally high pricing behavior is also demonstrated on crowded-sourced review platforms such as Google Maps and Yelp. Based on evaluations uploaded by users, both platforms evaluate a business using a star rating system where one star is the lowest score and five stars represent the highest score. This station holds below-average customers ratings: 2.1 stars on Google Maps based on 40 reviews and only one star on Yelp with 22 reviews. Almost all reviews on Google Maps and Yelp talk about the abnormally high pricing behavior of Station 82. For example, comments in Google Maps include "Price gouging! Go a few blocks further down Calle Real to the 7-11 ...", "Most expensive gas on earth" and "Watch out for price gouging. Gas is up to $2.00 more per gallon ..." (Google Maps, 2018). These online ratings and comments reveal negative impressions of gasoline prices at Station 82.

Two onsite observations were conducted to view the traffic around Station 82 during 2:40-5:00 p.m. on February 24, 2017 (Saturday) and 3:20-6:10 p.m. on February 27, 2017 (Tuesday). There were about 14 vehicles per hour entering Station 82 both days, among which only 5 vehicles per hour on average purchased gasoline. For vehicles buying gasoline at Station 82, about 70% came from U.S. Route 101, supporting the speculation that highway traffic provides primary target customers for this station. The other 30% came from local roads, more specifically, 15% from Glen Annie Road and 15% from Storke Road. It is interesting to observe that most drivers who stopped at Station 82 either bought goods from the convenience store then left or simply left without buying gasoline. This might imply that people were discouraged from filling up given Station 82's extremely high prices.

Targeting certain groups might also be an explanation for unreasonably high pricing behavior at Station 42 (76), located near the intersection of Carpinteria Avenue and Linden Avenue. This is the most active commercial area of Carpinteria. Further, Linden Avenue is the home to various restaurants, bars and other business activities, plus provides direct access to the beach. Not surprisingly, there is large traffic count at the intersection of Linden Avenue and U.S. Route 101 (64,700 vehicles per year), reflecting the popularity of this area.

Low market competition also likely helps to explain abnormal pricing behavior for Stations 42 and 82. Station 42 is one of the first encountered gasoline stations for northbound travelers along U.S. Route 101, and the only station providing major brand gasoline. Station 82 is one of the last stations when travelers leave the urban area heading north, and also is a major brand. More rural areas observe low market competition. For example, Station 35 shares the local market in Santa Ynez with only one competitor.

Station access is also of particular importance. Stations 42 and 82 are conveniently located near U.S. Route 101 exits. They are easy to access by significant traffic flows. Near the junction of State Routes 154 and 246, Station 35 (Chevron) has reasonable traffic access, but the town of Santa Ynez is somewhat isolated making access to local shops and restaurants an important factor in observed behavior.

Spatial location for gas stations does appear to explain price gouging behavior. Based on the three detected abnormal pricing cases, price gouging is explained in large part by location characteristics, including targeting certain groups, low market competition and ease of access.

It is also noteworthy that the detected three gougers, Stations 35, 42 and 82, all sell major-brand gasoline. This reveals that major oil companies appear to be more apt to set high prices in the region. The 32 cents per gallon difference between prices of major brands and minor brands explains part of this, but clearly there is more to the story in the case of price gougers.

Chapter 7

Conclusions

This thesis investigated significant factors for regional gasoline price variation. A framework integrating ESDA, remote sensing, GIS and spatial statistics was developed to analyze the gasoline market in Santa Barbara County. Diverse data from VGI, field survey, external sources and remote sensing was managed, converted, and manipulated using GIS tools and operations, generating predictors that characterize station density, local competition, station characteristics, demographics, land use, transportation and gasoline brand. An empirical regression model was derived involving these predictors in order to explore factors explaining regional gasoline price differentials. As an initial attempt at detecting non-emergency/disaster triggered gasoline price gouging, conditions considering regression results and comparison between pricing behavior with average price were proposed. Finally, the importance of spatial factors in understanding potential price gouging was detailed. The hope is that this work provides government agencies, urban planners and policy makers with capabilities to investigate regional gasoline price variation and potential price gouging behavior.

This thesis offers a first attempt at detecting potential gasoline price gouging and evaluating the importance of spatial factors associated with these conditions. Stations 35, 42 and 82 were identified as likely gougers, out of the 108 stations in the region. The importance of a station location in understanding potential price gouging was significant. Three potential factors were targeting certain groups, low market competition and ease of access. Particularly noteworthy is that Station 82 appears to take advantage of its location to target certain groups, including traffic from U.S. Route 101 and local streets.

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