The Link Between Seller Density, Price Elasticity, and Market Prices in Retail Gasoline Markets

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Abstract

From 1995 to 1999, regular unleaded self-serve gasoline prices at retail gasoline outlets in the Los Angeles area averaged 7.7 percent below similar prices in the San Diego area and 6.3 percent below prices in the San Francisco area. Economic theory suggests that there are two potential sources of such price differences: differences in the marginal cost of supplying gasoline to the three areas and differences in the character of demand across the three areas. In this paper we focus on the second potential source of price differences: differences in demand. Using data on these gasoline markets and original field experiment data collected around a series of exogenously imposed price changes across multiple stations in these markets, we are able to demonstrate support for the demand-based theoretical predictions.

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During the period from 1995 to 1999, retail prices for regular-grade unleaded self-serve gasoline at gasoline outlets in the Los Angeles area averaged 7.7 percent below similar prices in the San Diego area and 6.3 percent below prices in the San Francisco Bay area. In this paper we focus on explaining these differences, relying on both differences in the marginal cost of supplying gasoline and on differences in demand. Section 1 constructs a simple monopolistic competition model of price determination at retail gasoline stations to illustrate the link between the price charged and the price elasticity of demand. Section 1 also introduces a key determinant of the price elasticity of demand, the density of alternative sellers, and formulates an argument for the existence of price differences across markets.

Section 2 reviews the construction of an extensive data set identifying station locations across three California areas – Los Angeles, San Diego, and the San Francisco area. The data set is used to determine the number of other stations found within a specific distance of each station. This is our empirical measure of the density of alternative sellers for each station. An important fact is that station density in the Los Angeles area exceeds that in either the San Francisco or San Diego areas.

Section 3 introduces a second data set containing daily prices and sales for a sample of 54 "control" stations drawn from the three areas during three months in early 1999 as well as the prices charged by stations in close proximity to each of these 54 stations.[1] We refer to these 54 stations as "control" stations because the price at each of these stations was exogenously increased and decreased by the authors of this paper during various intervals over this three-month period.

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[1] We are thankful to the company in question for recently allowing us to utilize these data for this paper.

For each of these 54 control stations, we collected daily information on gasoline sales as well as prices charged by the station and by all stations within two linear miles from each control station. This allows us to estimate price elasticities of demand.

The estimation of demand elasticities is typically plagued with identification problems, for the researcher rarely knows the cause of observed price changes. Specifically, the researcher rarely knows whether or not observed price changes are due to changes in demand. However, our procedure generates observations of different price/quantity combinations that can be used to estimate price elasticities of demand. Grouping the stations into three categories depending on the extent of the density of alternative sellers allows us to estimate the effect of seller density on the price elasticity of demand. A key finding is that, as predicted by the theory, stations with a higher number of alternative sellers have a higher price elasticity of demand.

Section 4 combines the results in Sections 2 and 3 to determine the extent to which demand conditions may explain the price differences between the Los Angeles and the San Diego and San Francisco areas. In particular, we construct an estimate of the "average" price elasticity of demand by area based on the proportion of stations with various densities that exist for the three areas and on our estimated price elasticities of demand for the different types of stations in terms of seller density. From this and the theoretical link established in Section 1 between the price elasticity of demand and price, we generate predicted price differences between stations in the Los Angeles area and stations in the San Francisco or San Diego areas. These calculations indicate that regular-grade prices in the San Francisco area should be 4.5 percent higher than in the Los Angeles area, and prices in the San Diego area should be 7.1 percent higher than in the Los Angeles area. Our predictions are similar to the actual average differences during the 1995 to 1999 period of 7.7 percent higher prices in the San Francisco area and 6.3 percent higher prices in the San Diego area.

Section 5 contains concluding remarks in which we report additional evidence of differences between the Los Angeles area and the San Diego and San Francisco areas. One issue considered in this concluding section is the potential long-run adjustments to lower prices in the Los Angeles area relative to the San Diego and San Francisco areas.

1. Price Elasticity of Demand and Seller Density

Our setting is a market for a good that involves *L* consumers, each purchasing one unit of the good. Let *N* be the total number of sellers in the market ($N \geq 2$), such that sales of the representative seller equal *L*/*N*. For seller *i*, the production of q_i units of output has a common fixed cost component, *k*, and a constant marginal cost component, α . That is,

(1) $$C(q_i) = k + \alpha q_i \ ,$$

where $k > 0$ and $\alpha > 0$.

In general, the demand function faced by seller *i* will depend on the number of consumers and sellers in the market (*L* and *N*, respectively), the price charged by seller *i*, p_i, and the vector of prices charged by the other sellers, p_{-i} . In addition, the demand function will depend on consumers' common consumption values of the good, *r*, and consumers' costs to visiting the *N* sellers. Let *v* denote the cost to a consumer of visiting a seller. By assumption, a consumer's cost to visiting a particular seller is the realization of a random variable drawn from the continuous distribution $F(v)$.[2]

We assume that each consumer knows the prices and visiting costs of all sellers at the time of their decision to purchase. As such, a consumer with realized visiting costs v_i , $i = 1,\ldots, N$

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[2] The existence of such realized product differentiation is the key assumption that provides a rationale for a finite price elasticity of demand, as illustrated by Perloff and Salop (1985), Anderson and Renault (1999) and Barron, Taylor and Umbeck (2002), among others.

will purchase from seller *i* only if $p_i + v_i \leq \min_{k \neq i}[p_k + v_k]$ and $r \geq p_i + v_i$. Thus, given the second condition holds, the probability that consumer *j* buys from seller *i* is given by

(2) $$q_i^j = \int \prod_{k \neq i}[1 - F(p_i + v - p_k)]dF(v).$$

Summing across *L* consumers who each purchase one unit of the good, the expected demand for seller *i* becomes

(3) $$q_i = \sum_{j=1}^{L} q_i^j.$$

Each period, sellers choose a pricing strategy that maximizes profits taking as given the pricing strategies of other sellers. Specifically, each seller sets a unique price that maximizes profits given the resulting level of expected demand. Such a pure-strategy equilibrium means that for seller *i*, the maximization problem is:

(4) $$\max_{p_i} \; \pi_i = p_i \, q_i - C(q_i),$$

where (1) and (3) define the cost and demand functions, respectively. Seller *i*'s profit-maximizing price satisfies the standard first-order condition:

(5) $$p_i = m_i \alpha,$$

where $m_i = e_i/(e_i - 1) > 1$, and $e_i = -(\partial q_i / \partial p_i)(p_i / q_i)$ is firm *i*'s price elasticity of demand.

Equation (5) is the familiar expression stating that the optimal price equals the firm's marginal cost multiplied by a markup factor, m_i, which, in turn, is decreasing in the firm's price elasticity of demand, e_i. That is, where consumers are more responsive to adjustments in p_i, firm *i* will optimally choose a smaller markup over marginal cost. Beside the pricing decision, a seller decides whether to participate in the market.

As Perloff and Salop (1985) have shown, given identical marginal costs and demands for each seller, the market equilibrium has all firms charging the same price, with expected sales by each seller equal to *L*/*N*. This common price in the market is simply

(6) $$p = m\alpha \; .$$

The zero-return condition then determines the number of sellers, with the resulting equilibrium characterized by a price set by all sellers that is equal to the common marginal cost α plus average fixed cost *k*/(*L*/*N*). We assume in equilibrium that the consumption value of the good, *r*, exceeds the upper bound of the distribution of visiting costs plus equilibrium price, such that all consumers purchase from one of the *N* sellers.

Equation (6) reveals two types of asymmetry across markets that can result in differences in prices between markets. The first type of asymmetry is heterogeneity across markets in the marginal production cost, α. The second type is heterogeneity across markets in price elasticities of demand and thus mark-ups, a heterogeneity that can arise either from differences in the number of sellers in a market or differences in the distribution of consumers' visiting costs across markets, $F(v)$.[3]

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[3] Note that our focus here is on explaining price differences across markets, not price differences at different sellers in the same market, although the two can be derived from similar heterogeneity in costs and demand. A number of studies have considered price dispersion within particular markets. For instance, using city-level data, Marvel (1976) finds support for increased frequency of search (proxied by a larger volume of purchases) and lower search costs (measured by greater correlation of successive prices in the price distribution) reducing prices and price dispersion. Png and Reitman (1994), using station-level data from Massachusetts, find evidence that stations differentiate themselves on the basis of consumers' willingness to wait in line to buy gasoline. Contrary to Marvel's results, however, they find that prices are more dispersed in markets with a greater number of competitors, supporting their service-time differentiation hypothesis. Adams (1997), using a sample of 20 convenience stores that sell gasoline, finds that grocery items sold in the convenience stores have a higher degree of price dispersion than gasoline. Adams attributes this difference to the higher search costs associated with purchasing convenience store items relative to those search costs incurred when shopping for gasoline. For empirical studies of other industries that have investigated the link between search costs or market structure and the resulting price distribution consult Sorensen (2000), Walsh and Whelan (1999), Giulietti and Waterson (1997), Borenstein and Rose (1994), Dahlby and West (1986).

1.1 Differences in Prices Across Markets: Heterogeneous Marginal Cost

First, consider two monopolistically competitive markets where the markets differ in the common marginal cost of sellers in each market. Equation (6) indicates that the resulting equilibrium price will be lower in the market with the lower marginal cost. Thus, if marginal costs are lower in retail gasoline markets in the Los Angeles area relative to the San Diego and San Francisco areas of California, prices will be as well. In fact, such marginal cost differences can be traced to differences in transportation costs, with industry estimates of the cost of transporting fuel from Los Angeles to San Diego, for example, being as high as 2 cents per gallon.[4] Note from (6) that, given $m > 1$, such a difference can lead to a price difference greater than 2 cents. However, the size of the price differences in the late 1990s between Los Angeles and San Diego often exceeded three times this potential 2-cent marginal cost difference. From (6) this implies an elasticity of demand of less than 1.5. As we later show, such a low elasticity of demand for an individual gasoline station is not consistent with the evidence. Thus, we focus on the second potential explanation for price differences across markets.

1.2 Differences in Prices Across Markets: Heterogeneous demand

Now consider two monopolistically competitive markets in which there is a difference in the market size that leads to a difference in the number of sellers in the market. Perloff and Salop (1985) show that for the symmetric case, if one assumes visiting costs are bounded, then an increase in the number of sellers that accompanies an increase in market size will tend to

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[4] As there are no refineries in the San Diego area, San Diego County receives about 92 percent of its gasoline from a pipeline that runs from the Los Angeles refining center to distribution terminals located in the Mission Valley and San Diego Harbor. The rest of the gasoline (about 8 percent) is delivered to the area by tanker trucks. The shipping cost by pipeline from the Los Angeles refineries to the San Diego terminals is about 1 cent more per gallon than the cost to ship to the Los Angeles area terminals from the same refineries. Shipping gasoline to the San Diego region by tanker truck costs from 2 to 4 cents per gallon (Rohy, (1996)).

increase the price elasticity of demand, and thus according to (6) lead to a lower equilibrium price.[5] Intuitively, the higher price elasticity of demand arises as an increase in the number of sellers introduces more "close substitutes" for buyers. Factoring in the zero-return constraint, the result is that an increase in market size will tend not only to lower the equilibrium price but also raise the number of consumers per seller.[6]

Further consideration suggests an additional, indirect effect of increased seller density on the price elasticity of demand arising from a change in the distribution of visiting costs for consumers who define a market in terms of a fixed subset of sellers $C \leq N$ to consider. In this case, an increase in the number of sellers within a specific geographic region will tend to lower the average and maximum costs to consumers of "visiting" their fixed set of sellers. If v^o is the original visiting cost for a consumer visiting one of the C closest firms, then an increase in the density of sellers can be viewed as leading to the new visiting costs $v = \beta v^o$, with $1 > \beta > 0$. Following Perloff and Salop (1985), we interpret this change as a reduction in consumers' preference intensities for particular sellers. Such a reduction in preference intensity can be shown to lead to a higher price elasticity of demand and thus lower prices.

In summary, a key determinant of price differences across markets characterized as monopolistically competitive is the number of alternative sellers in close proximity. We refer to this determinant as the "density" of alternative sellers. A reduction in the density of alternative sellers implies that consumers experience higher search costs, implying a lower price elasticity of demand. We thus have the following prediction:

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[5] Note that this result holds in the limiting case. That is, this result holds as L and N approach infinity.
[6] Perloff and Salop (1985) also show that where there are demand asymmetries, holding constant the number of different seller types, an increase in the number of sellers of each type will tend to increase the price elasticity across sellers, and thus reduce mark-ups.

> Hypothesis: An increase in the density of alternative sellers will increase a seller's price elasticity of demand.

By extension, where station density is higher average prices will be lower as individual sellers face consumers who are generally more responsive to a given change in price.

2. Measuring the Density of Alternative Sellers in Retail Gasoline Markets

As indicated in the prior section, economic theory suggests that the density of alternative sellers affects the price elasticity of demand faced by an individual seller, and thus the optimal price level. Testing this theory at retail gasoline stations requires that we obtain a measure of the density of alternative sellers for different stations. To do so, we adopt the convention of identifying alternative sellers for each station in terms of their proximity to the station. In particular, we count as alternative sellers only stations within a specific radius of each station. The density of a station's alternative sellers is then simply the number of such stations that meets this proximity requirement.

We determine the density of alternative sellers for three geographic areas in California, Los Angeles, San Diego, and the San Francisco area. Three data sources are used to develop such a census. From Lundberg, Inc., we obtained a census of stations in San Diego and the Los Angeles areas taken in 1996. Lundberg also provided 1997 census data for the San Francisco and San Diego areas. From Whitney-Leigh, we obtained an annual census of stations for the San Diego, Los Angeles, and San Francisco areas for the years 1995 to 1998. A third company, MPSI, provided a census of specific areas in the Los Angeles and San Diego areas taken in 1999.

The stations recorded in each census from these three companies were matched to each other and to a list of proprietary station data provided to us by a large gasoline retailer using a variety of matching algorithms based on street address, crossing street, city, and brand. Substantial care was taken in the matching process to make sure that the same station identified by two different sources would not be counted as two separate stations. However, there were stations that did not match across data sets because the precise areas covered by each census differed or due to the entry or exit of stations between the times each census was taken.

The time-consuming process of matching stations across the three censuses was done for a variety of reasons. First, all three censuses contain some stations in areas not included in the other two censuses, so each census provides additional observations. Second, while the Lundberg census provides key information on location (latitude and longitude) not contained in the Whitney-Leigh census, the 1998 Whitney-Leigh census provides more current information on existing stations than the Lundberg 1996 census. Finally, matching stations from different censuses allows us to check the validity of key data, in particular the latitude and longitude data provided in the MPSI and Lundberg censuses. Once the census data were matched, the data were then matched to the 721 stations contained in the 1999 proprietary price surveys as well as to a listing of California company-operated stations provided by the large gasoline retailer.[7] Table 1 reports the various types of matches of the census data with each other and with the proprietary price survey. The source of the 1999 proprietary price survey is discussed in Section 3.

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[7] As mentioned above, the researchers controlled the retail prices at 54 control stations. To measure the impact of these price changes, we surveyed each day of the week all of the other stations within a 2 mile radius around the control station. We call this survey of 721 stations the proprietary price survey.

Table 1
Identification of Stations From Various Censuses

Source or Sources of Station Information	Stations not in 1999 proprietary price survey	Stations in 1999 proprietary price survey	Total number of stations
Lundberg, MPSI, and Whitney-Leigh census	3,312	501	3,813
Lundberg and MPSI census only	35	1	36
Lundberg and Whitney-Leigh census only	2,384	212	2,596
MPSI and Whitney-Leigh census only	113	1	114
Whitney-Leigh and list of company-operated stations of gasoline retailer only	1		1
Lundberg census only	676	5	681
MPSI census only	131	1	132
Whitney-Leigh census only	142		142
List of company-operated stations of gasoline retailer only	4		4
Total Number of Stations	6,798	721	7,519

Our next step was to delete stations in our combined data set that appear not to have been in operation during the period of our price survey (Spring, 1999). First, we deleted 36 stations only found in the Whitney-Leigh census that were reported in that census as “not in operation.” Next, we deleted 10 stations in the various Lundberg censuses that could not be matched with any other census and that the 1999 proprietary price survey specifically identified as “not in operation” at the time of the survey. Third, we deleted 125 stations in the Lundberg census that could not be matched with either of the other two censuses and that the Lundberg census cited as “not in operation.” Fourth, we deleted 148 stations that were in both the Lundberg and Whitney-Leigh census and were cited as stations “not in operation” at the time of the census.

Next, we dropped 20 stations that were in both the Whitney-Leigh census and Lundberg, but for whom the match to the Whitney-Leigh census was not to the most recent (1998) Whitney-Leigh census. The presumption was that these stations were missing from the most recent Whitney-Leigh census because they had gone out of operation. We also dropped 44 stations with the brand CFN that only appeared in the Lundberg census. Apparently stations selling this brand closed down subsequent to Lundberg's 1996 census, and thus did not appear in either the Whitney-Leigh or the MPSI census. Finally, we dropped 4 company-operated stations of the gasoline retailer that were not in any of the areas covered by the census and 20 Whitney-Leigh stations that were in counties outside those covered by the Lundberg and MPSI surveys.

Among the stations left, a number were in both the Lundberg census and the MPSI census. We thus had two sets of latitudes and longitudes for these stations, and could check the accuracy of these location data. If the two censuses indicated locations that differed by more than one fifth of a mile, an independent assessment of location was made using the most recent mapping programs and address information taken from the matched data in order to determine the correct latitude and longitude data. This mapping process was also used to fill in missing latitude and longitude data, especially for the Whitney-Leigh stations that did not match with either the Lundberg or MPSI census stations. There remained, however, 67 stations for which a latitude and longitude could not be computed. These were typically stations in rural areas with addresses that provided neither a street number nor a crossing street. Without such exact locational data, these stations had to be excluded from the calculations of the density of alternative sellers.

The outcome of the above elimination of stations not in operation as of 1999 or without location data is the identification of 7,045 stations across the three areas (Los Angeles, San Diego, and the San Francisco areas). Table 2 reports the various types of matches for these stations. One important item to note is that all 721 stations in the 1999 proprietary price survey are contained in the census data analyzed.

Table 2
Stations in Operation in 1999 From Various Censuses

Source or Sources of Station Information	Stations not in 1999 proprietary price survey	Stations In 1999 proprietary price survey	Total number of stations
Lundberg, MPSI, and Whitney-Leigh census	3,312	501	3,813
Lundberg and MPSI census only	35	1	36
Lundberg and Whitney-Leigh census only	2,185	212	2,397
MPSI and Whitney-Leigh census only	113	1	114
Whitney-Leigh and list of company-operated stations only	1		1
Lundberg census only	479	5	484
MPSI census only	131	1	132
Whitney-Leigh census only	68		68
Total Number of Stations	6,324	721	7,045

The data set summarized in Table 2 allows us to accurately calculate the number of alternative stations within a particular radius of each station in the Los Angeles, San Diego, and San Francisco areas in early 1999. Table 3 summarizes the distribution of the density of alternative sellers across these three areas – Los Angeles, San Diego, and San Francisco – in terms of the average number of other gasoline stations within one and one-half and two miles of each station. Table 3 also provides information on the fraction of stations that have less than 10 other stations, 10 to 15 other stations, and over 15 other stations within a 1.5-mile radius. An interesting aspect of Table 3 is the difference between Los Angeles and the other two areas. Within a 1.5-mile radius, the typical Los Angeles area station has over two more neighboring stations than the typical station in either the San Diego area or the San Francisco area. These differences are statistically significant.

Table 3
Distribution of Station Density By Location

Location	Average number of stations within a 1.5 mile radius	Average number of stations within a 2 mile radius	Proportion of stations having fewer than 10 other stations within 1.5 mile radius	Proportion of stations having 10 to 15 other stations within 1.5 mile radius	Proportion of stations having over 15 other stations within 1.5 mile radius	Total number of stations
San Francisco	11.47	18.17	.385	.361	.254	1,651
San Diego	11.23	17.45	.477	.296	.227	761
Los Angeles	13.85	22.21	.300	.273	.427	4,633
All Three Areas	13.01	20.75	.339	.296	.365	7,045

Source: Lundberg, MPSI, and Whitney-Leigh censuses.

3. A Test of the Impact of Seller Density on Price Elasticity of Demand

The finding of a higher station density in the Los Angeles area provides one rationale for lower prices in the Los Angeles area if one can establish empirically the link between station density and the price elasticity of demand. However, as is well known in the econometric literature, obtaining estimates of the price elasticity of demand is a difficult task. The reason for this is that to estimate the price elasticity of demand, we must observe the effect of changes in prices on sales holding constant those other factors that can influence the level of demand. But often a price change occurs precisely because of a change in one of the factors affecting the level of demand, and it is thus difficult to be sure that observed price changes occurred independent of such factors.

Fortunately, a large gasoline retailer was interested in obtaining an estimate of the price elasticity of demand at its various stations and allowed us to randomly change the prices charged at some of its company-operated stations. In particular, the company permitted us to control and survey prices at 54 stations of our choosing over a three-month period from February 8, 1999 to April 27, 1999. The 54 stations we chose consisted of 9 stations from the San Francisco area, 25 stations from the Los Angeles area, and 20 stations from the San Diego area. In choosing stations, an attempt was made to stratify stations by volume and number of alternative sellers.

Once the sample of stations was chosen, a procedure for instituting price changes at the individual stations was devised. The sample of 54 stations was divided into two groups. Each week, the prices at stations in one of these two groups were increased or decreased by 2 cents from the price that existed on the prior day. To assure that company personnel would not know ahead of time the direction of a price change, the exact identity of the stations in terms of the direction of its price change was known only to us until the price change was implemented. This new price was then maintained for one week after which control of the price at the station would revert to the company for a week and its standard company procedures would determine the price. The process would then be repeated. Thus, for each station, a week of price control would be followed by a week of "normalizing."[8]

During this three-month period of the experiment, daily volumes sold at the 54 stations were collected. In addition, the company sent out surveyors each weekday to record the prices charged by other stations within a two-mile radius of the station.[9] We thus have a data set that includes prices and sales of 54 control stations as well as the prices at stations surrounding each control station over a 3-month period (79 days). An important feature of this data set is that one

[8] There was one exception to this pattern. A major explosion at a San Francisco area refinery (Tosco's Avon refinery, 23 February, 1999), followed by lesser problems at other refineries resulted in a substantial supply disruption in the middle of the experiment period. Control of stations was suspended for approximately three weeks after this event although we continued to collect the relevant market data from our survey.
[9] Prices for weekends were interpolated from the prices charged on Friday and Monday.

can be confident that the price changes in this data set are largely the result of exogenous "supply-side" factors rather than due to changes in factors affecting demand.[10] This data set is referred to as the 1999 proprietary price survey.

To estimate the price elasticity of demand for a given grade of gasoline, we specify a log-linear form for the demand equation of a particular station of type *k* such that

$$\ln(S_{it}) = \delta - \beta_k \ln(P_{it}) + \gamma_k \ln(\overline{P}_{it}) + \lambda \ln(X_{it}) + \upsilon_{it} \quad , \tag{7}$$

where S_{it} denotes the sales of gasoline by control station *i* during the period (day) *t*, P_{it} denotes the price of the i^{th} control station during period *t*, $\overline{P}_{it}$ denotes the average price of the alternative sellers for control station *i* during period *t,* and X_{it} denotes a vector of station characteristics. The parameters β_k and γ_k denote the own and cross-price elasticities of demand respectively for a station of type *k*, while $\upsilon_{it} = \varepsilon_{it} + u_i$ is the residual, where ε_{it} is the traditional error term and u_i is an error term representing the extent to which the intercept of the i^{th} control station differs from the overall intercept. As such, equation (7) implicitly allows a unique intercept term for each control station to allow for differences in average sales across stations to be independent of price differences.

We determine a station's type by the density of its alternative sellers. In particular, we divide stations in our sample into three groups, those with a low density (less than 10 other stations within a 1.5 mile radius, $k = l$), those with a mid-level density of stations (between 10 to 15 other stations within a 1.5 mile radius, $k = m$), and stations with a high density of alternative

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[10] Even the refinery explosions turned out to be fortuitous for our study because the large price increases were attributable to a supply change. It allowed us larger relative price changes than otherwise would have occurred.

sellers (more than 15 other stations within a 1.5-mile radius, $k = h$). These three groups match those reported in Table 5.

Our discussion of the role of density as directly influencing the price elasticity of demand leads to the predictions that in estimating (7) separately for each grade of gasoline, we expect $\beta_h > \beta_m > \beta_l$ and $\gamma_h > \gamma_m > \gamma_l$. That is, we expect these elasticities to be greater at stations in markets where consumers face a higher density of alternatives. We also expect that the estimated elasticities will be universally larger the lower is the grade of gasoline, reflecting greater price sensitivity of consumers at lower grades of gasoline.

Equation (7) is estimated using a random-effects model with the Huber/White correction.[11] In an attempt to control for within-station substitution of purchases across grades of available gasoline we also estimate (7) for each grade with controls for the relative prices of the grade of gasoline in question to the prices of the other available grades at the control station on the same day. Our *a priori* expectations are captured in Table 4. For example, where the ratio of regular-grade price to mid-grade price rises we expect that sales of regular grade gasoline will decrease (reflecting the relative attractiveness of mid-grade) and sales of mid-grade gasoline will increase. Further, where the ratio of mid-grade price to premium-grade price rises we expect that sales of mid-grade gasoline will decrease (reflecting the relative attractiveness of premium-grade) and sales of premium-grade gasoline will increase. We also expect the estimated elasticities to fall with the inclusion of such controls since changes in sales volumes should, in part, be due to changes in the prices of alternative-grade gasoline and to the extent prices are correlated with

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[11] The Huber/White estimator of variance produces consistent standard errors even if the residuals across groups are not identically distributed or the correlations within group are not as hypothesized by the specified correlation structure. Similar results are obtained if we estimate a simpler fixed-effects model.

said ratios an omitted variable bias would attribute significance to own-grade prices erroneously. These results are reported in columns (2), (4) and (6) of Table 5.

Table 4
Expected Signs for Controls for Within-Station Substitution.

	Log of sales volume (self-serve gasoline) at control station		
Independent variable	Regular-Grade	Mid-Grade	Premium-Grade
Log of Regular to Mid-grade price ratio	-	+	
Log of Mid to Premium-grade price ratio		-	+

The results of our test, reported in Table 5, provide strong support for the hypothesis that the density of a station's alternative sellers directly affects its price elasticity of demand. For instance, according to Column (2) of Table 5, a one percent increase in a station's regular-grade price will, other things equal, reduce sales of regular-grade gasoline by 2 percent at stations with low density (small number of alternative sellers), 3.5 percent at stations with mid-level density, and 4.9 percent at stations with a high density. Results are comparable for mid-grade and premium-grade gasoline. From Column (4), a one percent increase in a station's mid-grade price will, other things equal, reduce sales of mid-grade gasoline by 2.2 percent at stations with low density, 2.3 percent at stations with mid-level density, and 3.6 percent at stations with a high density. The corresponding elasticities for premium-grade gasoline, from Column (6), are 3.4, 3.7 and 4.3, respectively.[12]

[12] Note that for mid and premium grade gasolines, while the point estimates are increasing in absolute magnitude across market type, the estimated elasticities for stations with low and mid density alternatives are not significantly different.

In general, we find that the estimated elasticities for mid-grade gasoline are less than those of both regular and premium-grade gasoline. Specifically, average price elasticity of mid-grade gasoline in our sample is 2.78 whereas the elasticities for regular and premium-grades are 3.72 and 3.86, respectively. However, one might expect that due to mid-grade gasoline having a close substitute both above and below in quality space, consumers' sensitivity to changes in price would be greater, all else equal. Our evidence is contrary to this notion.

Table 5
Estimating a Random-Effects Model for Gasoline Sales at Stations with Different Densities of Alternative Stations.

Reported coefficients represent elasticities (with the exception of the intercept). Absolute value of *z*-statistic is in parentheses. The Huber/White/sandwich estimator of variance is used. Coefficients for 6 day-of-week indicator variables are included in the estimation of all columns but not reported.

	Log of sales volume (self-serve gasoline) at control station					
Independent variable	Regular-Grade		Mid-Grade		Premium-Grade	
	(1)	(2)	(3)	(4)	(5)	(6)
Log of self-serve price						
Low density of alternatives	-2.142 (8.38)***	-2.012 (7.80)***	-2.471 (8.04)***	-2.223 (7.17)***	-3.417 (11.43)***	-3.440 (11.32)***
Mid-level density of alternatives	-3.586 (18.71)***	-3.495 (18.09)***	-2.529 (10.42)***	-2.257 (9.14)***	-3.679 (14.04)***	-3.688 (14.03)***
High density alternatives	-5.045 (25.66)***	-4.941 (24.88)***	-3.824 (15.73)***	-3.628 (14.84)***	-4.331 (16.70)***	-4.345 (16.66)***
Log of average self-serve price at alternative stations within 1.5 miles						
Low density of alternatives	2.407 (8.92)***	2.282 (8.40)***	1.614 (4.71)***	1.428 (4.13)***	1.793 (5.33)***	1.830 (5.27)***
Mid-level density of alternatives	3.777 (18.42)***	3.707 (18.03)***	1.775 (6.43)***	1.550 (5.51)***	2.148 (7.17)***	2.172 (7.13)***
High density alternatives	5.166 (24.06)***	5.088 (23.59)***	3.101 (11.22)***	2.954 (10.60)***	2.765 (9.30)***	2.795 (9.21)***
Log of Regular-Mid price ratio		-0.698 (3.50)***		0.993 (3.94)***		
Log of Mid-Premium price ratio				-2.012 (4.66)***		-0.214 (0.46)
Constant	8.273 (217.64)***	8.209 (193.74)***	6.968 (136.73)***	6.904 (99.97)***	6.865 (111.93)***	6.843 (87.44)***
Observations / number of unique control stations	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54
	Wald $\chi 2(12)$ = 1,574.9	Wald $\chi 2(13)$ = 1,592.0	Wald $\chi 2(12)$ = 3,309.5	Wald $\chi 2(14)$ = 3,372.5	Wald $\chi 2(12)$ = 7,907.9	Wald $\chi 2(13)$ = 7,909.8
Mean of dependent variable	8.381		6.721		6.213	

Results are robust to dropping all observations corresponding to Saturday and Sunday and to the inclusion of controls for number of nozzles, hours of operation and C-store existence. Comparable results are reported in Table A3 in the appendix.
* significant at 10% level.
** significant at 5% level.
*** significant at 1% level.

Intriguingly, we do find significant predictive power in our controls for within-station substitution across grades of gasoline. Specifically, our *a priori* expectations are supported in the data insofar as three of the four predictions are significant and of the predicted signs. The fourth estimate is insignificantly different from zero. Controlling for own-grade prices, as the ratio of regular-grade price to mid-grade price rises, sales of regular grade gasoline decrease and sales of mid-grade gasoline increase. Further, as the ratio of mid-grade price to premium-grade price rises sales of mid-grade grade gasoline decrease. Also of note is that the point estimates of elasticity do generally fall with the inclusion of controls for within-station substitution. The single exception is premium-grade gasoline, where there is a marginal increase in estimated price-elasticities, although the increase is not significantly different from zero.

It is important to recognize that the estimated price elasticities of demand derive from customers' responses to a price change over relatively short periods of time. Thus, while suggestive, these estimated magnitudes probably are below the true levels of price elasticity of demand. However, for our purposes, it is not so much the levels of the price elasticities of demand as it is the differences in the price elasticities of demand across stations of different types that is important for the analysis to follow. In this regard, any bias introduced by the limited time period over which we consider customers' responses is of less concern.

4. Predicted Versus Actual Differences in Self-Serve Prices Across Areas

As reported in the introduction, a substantial price difference emerged between retail gasoline prices in the Los Angeles area compared to prices in the San Diego and San Francisco areas during the latter part of the 1990s. Using Lundberg, Inc. bi-monthly price surveys, Table 6 summarizes the annual average retail prices for self-serve gasoline in these three areas from 1995 to 1999.[13] Note that during the 1995 to 1999 period, regular-grade prices in the Los Angeles area averaged 7.1 percent below prices in the San Francisco area. During this same period, regular-grade prices in the Los Angeles area averaged 5.8 percent below prices in the San Diego area.

Table 6
Annual Self-Serve Regular Prices Across Areas

Year	Average Self-serve Regular Price San Francisco Area	Average Self-serve Regular Price Los Angles Area	Average Self-serve Regular Price San Diego Area	Average Self-serve Regular Price All Areas
1995	$ 1.241	$ 1.208	$ 1.264	$ 1.225
1996	$ 1.388	$ 1.279	$ 1.361	$ 1.321
1997	$ 1.405	$ 1.318	$ 1.397	$ 1.353
1998	$ 1.276	$ 1.122	$ 1.232	$ 1.181
1999	$ 1.387	$ 1.281	$ 1.332	$ 1.318
Overall	$ 1.332	$ 1.237	$ 1.314	$ 1.275

Source: Lundberg Survey, Inc.

Figure 1 plots monthly Los Angeles self-serve regular prices for the period 1995 to 1999. Also plotted in Figure 1 are differences between the prices in the San Diego and San Francisco areas and the average price in the Los Angeles area. Interestingly, the largest differences between prices in San Diego and the San Francisco area and prices in the Los Angeles area tend to occur during times of rapidly falling LA prices.

We can combine our estimates of the price elasticities of demand for various types of stations reported in Table 5 with the proportion of stations of each type for the three areas listed in Table 3 to obtain a measure of the average price elasticity of demand by area. The first column in Table 7 reports this predicted average price elasticity of demand for the typical station

[13] The 1999 data are through the end of May 1999.

in each of the three areas.[14] Notice that the average price elasticity of station demand is higher in LA than in San Diego or the San Francisco areas.

Table 7
Differences in Price Elasticity, Predicted Prices, and Actual Prices Across Areas from Random-Effect Models

Area	Predicted average price elasticity of demand	Predicted price/marginal cost ratio (*m*)	Predicted percentage difference from LA area price	Actual percentage difference from LA area price (Lundberg 1995-99)
Regular-Grade Gasoline				
San Francisco	3.29	1.44	4.5% higher	7.7% higher
San Diego	3.12	1.47	7.1% higher	6.3% higher
Los Angeles	3.67	1.37	---	---
Mid-Grade Gasoline				
San Francisco	2.59	1.63	5.3% higher	6.6% higher
San Diego	2.55	1.64	6.4% higher	6.2% higher
Los Angeles	2.83	1.55	---	---
Premium-Grade Gasoline				
San Francisco	3.76	1.36	1.3% higher	6.7% higher
San Diego	3.72	1.37	1.7% higher	6.0% higher
Los Angeles	3.89	1.35	---	---

Given these average prices elasticities, equation (1) provides us with the predicted ratios of price to marginal cost for each area. The second column in Table 7 reports this calculation. From these predicted price-marginal cost ratios, the third column in Table 7 generates the predicted level in the prices in the San Francisco and San Diego areas relative to the Los Angeles

[14] From Table 5, Column (2)

area under the assumption of common costs, α . To account for the higher marginal costs of production in San Diego and San Francisco areas would increase the predicted difference. Thus, these reported predictions might be properly interpreted as lower bounds. Finally, the fourth column in Table 7 presents the actual extent to which prices in the San Francisco and San Diego areas exceeded the Los Angeles area over the 1995-1999 period according to Lundberg Survey, Inc.

The similarity between predicted and actual price differences in Table 7 supports the notion that difference in demand conditions arising from differences in the density of stations and thus the price elasticity of demand may be one source of the observed higher prices of regular-grade gasoline in San Diego and the San Francisco areas relative to the Los Angeles area. The predicted difference in premium-grade gasoline is significantly less than the actual price differences.

5. Discussion and Conclusion

The preceding analysis suggests that the higher prices in San Diego and the San Francisco area relative to the Los Angeles area may simply reflect lower price elasticities of demand arising from lower station density. Specifically, elasticity considerations alone lead to predicted price differences between stations in the Los Angeles area and stations in the San Francisco or San Diego areas of magnitudes similar to those observed over the years 1995 through 1999. These calculations suggest that prices in the San Francisco area should be 4.5 percent higher than in the Los Angeles area, and prices in the San Diego area should be 7.1 percent higher than those in the Los Angeles area.

Other things equal, such price differences should translate into a lower return to stations in the Los Angeles area relative to the other two areas. Economic theory suggests that in the long run these differences in returns will be dissipated. There are several potential avenues through which this could occur. One way would be a decrease in the number of stations in the Los Angeles area relative to the San Francisco and San Diego areas. Figure 2 indicates that this in fact has occurred. Using Whitney-Leigh annual censuses of the three areas, evidence indicates a decrease in the number of stations in the Los Angeles area between 1995 and 1998 relative to the number in both the San Francisco or San Diego areas.

Further, there also exists evidence of entry restrictions in the San Diego and San Francisco areas. Note that if entry into these two areas were restricted we would expect to see the existing stations being utilized more intensively than stations in the LA area. From the Whitney-Leigh census data we can construct a measure of the capacity utilization of gasoline stations. This capacity measure uses information on hours of operation, monthly gasoline volume and number of fueling position to calculate the capacity utilization of a station in terms of the quantity of gasoline pumped per hour per fueling position.

Table 8 indicates the average capacity utilization of stations across the three areas. As the numbers reported in Table 8 make clear, stations in the San Diego and San Francisco areas were more heavily utilized relative to stations in Los Angeles during the 1995 to 1998 period. This observation is consistent with there being factors in the San Diego and San Francisco areas that limit the entry of new stations relative to the Los Angeles area. If there are such restrictions to entry in the San Francisco and San Diego areas, then competition for the relatively restricted number of prime service station locations in the San Diego and San Francisco areas will result in higher utilization rates and higher "fixed" costs for the station operators.

Table 8
Capacity Utilization by Area

Year	San Francisco Area average gasoline sales per fueling position per hour	Los Angeles Area average gasoline sales per fueling position per hour	San Diego Area average gasoline sales per fueling position per hour
1995	29.4	24.6	28.3
1996	29.1	26.7	25.5
1997	30.0	26.4	27.5

1998	31.4	26.8	30.8

Left to further study is the analysis of the pricing behavior of stations in close proximity to each of the 54 control stations around the time of our exogenous price changes. Thus far, to demonstrate significant reactions by neighboring stations to the exogenously imposed price changes at our control stations has proven difficult. We speculate that this is due to the period over which our analysis takes place, one in which prices are generally rising due to the Tosco Avon refinery explosion of 23 February 1999. This event does not keep us from maintaining conditions for proper analysis of price elasticity, as the refinery explosion is in fact a large exogenous supply shock. However, it does limit the extent to which we can draw conclusions regarding the price setting behavior of neighboring stations. Specifically, consider that a neighboring station may respond to an exogenous increase in the price of a particular control station. However, were prices in general to increase by magnitudes similar to those observed surrounding the events of 23 February, the exogenously imposed increase in price quickly becomes a “below market” price control. This is evidenced in the company’s requests for the researchers to release control over prices shortly following the explosion.

Appendix

Table A1 below indicates that for our sample of stations, the distribution of stations in terms of types of competitors does not match the overall distribution for the three areas obtained from the census data (see Table 3). While the census indicates station density is greatest in the Los Angeles area, our sample has the highest station density in the San Francisco area. As a consequence, an estimate of the price elasticities of demand for our sample of stations that is divided by area will tend to overstate the price elasticity of demand in the San Francisco area. The results reported in Table A2 support this contention.

Fixed-effect coefficients are reported in Table A3 and predicted prices differences from these fixed-effect models are provided in Table A4. Note that our results are robust to this estimation procedure.

Table A1
Distribution of Sample Stations' Station Density By Location

Area	Average number of stations within a 1.5 mile radius	Proportion of stations having fewer than 10 other stations within 1.5 mile radius	Proportion of stations having 10 to 15 other stations within 1.5 mile radius	Proportion of stations having over 15 other stations within 1.5 mile radius	Total number of stations
San Francisco	15.9	0	0.697	0.303	657
Los Angeles	13.3	0.198	0.410	0.391	1,728
San Diego	12.6	0.375	0.312	0.313	1,455
Total	13.5	0.231	0.422	0.347	3,840

Table A2

Estimating a Random-Effects Model for Gasoline Sales by Location.

Reported coefficients represent elasticities (with the exception of the intercept). Absolute value of *z*-statistic is in parentheses. The Huber/White/sandwich estimator of variance is used. Coefficients for 6 day-of-week indicator variables are included in the estimation of all columns but not reported.

	Log of sales volume (self-serve gasoline) at control station					
Independent variable	Regular-Grade		Mid-Grade		Premium-Grade	
	(1)	(2)	(3)	(4)	(5)	(6)
Log of self-serve price						
Los Angeles area	-3.973 (20.64)***	-3.822 (19.51)***	-3.290 (14.20)***	-3.052 (12.96)***	-3.939 (16.26)***	-3.932 (16.10)***
San Diego area	-2.995 (11.99)***	-2.839 (11.25)***	-1.929 (6.79)***	-1.721 (6.01)***	-2.549 (8.89)***	-2.527 (8.50)***
San Francisco area	-4.510 (18.06)***	-4.415 (17.63)***	-3.629 (11.82)***	-3.438 (11.18)***	-5.638 (16.04)***	-5.643 (16.03)***
Log of average self-serve price at alternative stations within 1.5 miles						
Los Angeles area	4.224 (20.13)***	4.083 (19.21)***	2.448 (9.17)***	2.273 (8.38)***	2.281 (8.11)***	2.265 (7.82)***
San Diego area	3.136 (12.08)***	3.008 (11.52)***	1.119 (3.57)***	0.948 (2.98)***	0.839 (2.62)***	0.808 (2.38)**
San Francisco area	4.630 (16.65)***	4.566 (16.43)***	3.034 (8.62)***	2.917 (8.28)***	4.482 (11.16)***	4.477 (11.13)***
Log of Regular-Mid price ratio		-0.834 (3.96)***		0.977 (3.79)***		
Log of Mid-Premium price ratio				-2.014 (4.47)***		0.126 (0.25)
Constant	8.183 (205.90)***	8.108 (183.60) ***	6.888 (142.48)***	6.821 (100.01)***	6.751 (111.37)***	6.764 (84.31)***
Observations / number of unique control stations	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54
	Wald $\chi2(6)$ = 977.4	Wald $\chi2(7)$ = 996.8	Wald $\chi2(6)$ = 2,896.4	Wald $\chi2(8)$ = 2,950.4	Wald $\chi2(6)$ = 6,969.8	Wald $\chi2(7)$ = 6,970.6
Mean of dependent variable	8.381		6.721		6.213	

Results are robust to dropping all observations corresponding to Saturday and Sunday and to the inclusion of controls for number of nozzles, hours of operation and C-store existence.
* significant at 10% level.
** significant at 5% level.
*** significant at 1% level.

Table A3
Estimating a Fixed-Effects Model for Gasoline Sales at Stations with Different Densities of Alternative Stations.

Reported coefficients represent elasticities (with the exception of the intercept). Absolute value of *z*-statistic is in parentheses. The Huber/White/sandwich estimator of variance is used. Coefficients for 6 day-of-week indicator variables are included in the estimation of all columns but not reported.

	Log of sales volume (self-serve gasoline) at control station					
Independent variable	Regular-Grade		Mid-Grade		Premium-Grade	
	(1)	(2)	(3)	(4)	(5)	(6)
Log of self-serve price						
Low density of alternatives	-2.056	-1.916	-2.421	-2.182	-3.305	-3.326
	(7.96)***	(7.34)***	(7.71)***	(6.90)***	(10.90)***	(10.80)***
Mid-level density of alternatives	-3.562	-3.467	-2.475	-2.205	-3.635	-3.644
	(18.39)***	(17.77)***	(9.96)***	(8.74)***	(13.62)***	(13.61)***
High density alternatives	-5.136	-5.026	-3.885	-3.693	-4.410	-4.421
	(25.85)***	(25.05)***	(15.66)***	(14.81)***	(16.73)***	(16.68)***
Log of average self-serve price at alternative stations within 1.5 miles						
Low density of alternatives	2.309	2.173	1.553	1.377	1.651	1.684
	(8.45)***	(7.89)***	(4.42)***	(3.89)***	(4.81)***	(4.77)***
Mid-level density of alternatives	3.747	3.675	1.709	1.488	2.095	2.116
	(18.07)***	(17.67)***	(6.03)***	(5.16)***	(6.84)***	(6.80)***
High density alternatives	5.272	5.189	3.174	3.032	2.865	2.889
	(24.26)***	(23.79)***	(11.22)***	(10.64)***	(9.45)***	(9.34)***
Log of Regular-Mid price ratio		-0.735		0.970		
		(3.68)***		(3.84)***		
Log of Mid-Premium price ratio				-2.003		-0.179
				(4.64)***		(0.39)
Constant	8.282	8.215	6.975	6.910	6.876	6.858
	(805.37)***	(392.70)***	(407.76)***	(139.45)***	(347.10)***	(132.7)***
Observations / number of unique control stations	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54	3,990 / 54
	F(12, 3924) = 131.8	F(13, 3923) = 123.11	F(12, 3924) = 276.52	F(13, 3923) = 241.38	F(12, 3924) = 662.24	F(13, 3923) = 611.18
Mean of dependent variable	8.381		6.721		6.213	

Results are robust to dropping all observations corresponding to Saturday and Sunday and to the inclusion of controls for number of nozzles, hours of operation and C-store existence.
* significant at 10% level.
** significant at 5% level.
*** significant at 1% level.

Table A4
Differences in Price Elasticity, Predicted Prices, and Actual Prices Across Areas from Fixed-Effect Models

Regular-Grade Gasoline				
Area	Predicted average price elasticity of demand	Predicted price/marginal cost ratio (*m*)	Predicted percentage difference from LA area price	Actual percentage difference from LA area price (1995-99)
San Francisco	3.27	1.44	4.8% higher	7.7% higher
San Diego	3.08	1.48	7.7% higher	6.3% higher
Los Angeles	3.67	1.37	---	---
Mid-Grade Gasoline				
Area	Predicted average price elasticity of demand	Predicted price/marginal cost ratio (*m*)	Predicted percentage difference from LA area price	Actual percentage difference from LA area price (1995-99)
San Francisco	2.57	1.64	5.8% higher	6.6% higher
San Diego	2.53	1.65	6.9% higher	6.2% higher
Los Angeles	2.83	1.55	---	---
Premium-Grade Gasoline				
Area	Predicted average price elasticity of demand	Predicted price/marginal cost ratio (*m*)	Predicted percentage difference from LA area price	Actual percentage difference from LA area price (1995-99)
San Francisco	3.72	1.37	1.5% higher	6.7% higher
San Diego	3.67	1.37	2.0% higher	6.0% higher
Los Angeles	3.88	1.35	---	---

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Figure 1
Los Angeles Self-Serve Regular Price and Difference Between Prices in the San Diego and Bay Areas and the Los Angeles Area

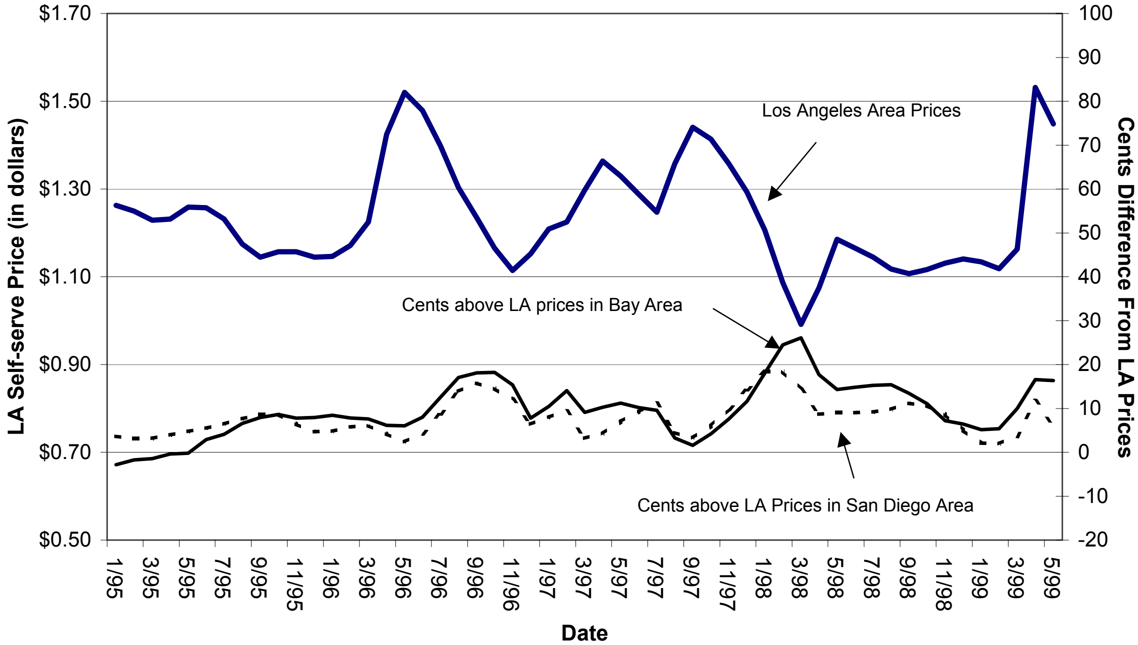

Figure 2
Ratios of the Number of Stations in the Los Angeles Area to the Number in the San Diego and Bay Areas, 1995-1998