Price Discrimination and Retail Configuration

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The hypothesis that price discrimination based on willingness to pay for quality can occur in multifirm markets is confirmed using microdata on gasoline retailing. A test that discriminates between price structures associated with discrimination and with cost-driven, competitive differentials is developed and implemented with controls for variation in outlet and market characteristics. A second test based on profitability variation rejects a competitive, peak-load pricing explanation for the observed price dispersion. The data suggest that price discrimination at the retail level adds at least 9¢ a gallon to the average price of full-service gasoline.

I. Introduction

There is a long-standing consensus among economists that a monopoly firm can price discriminate when resale of its product is difficult and consumers with different tastes can be separated. But the possibility of price discrimination in multifirm markets is less well established. Prior to the 1980s, many economists would have agreed with Bork's (1978) claim that persistent price differences in multifirm markets cannot be discriminatory. Recently, however, price discrimination equilibria have been analyzed in a variety of multifirm settings[1]

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[1] The analysis has been extended to a duopoly setting by Jaskold-Gabszewicz and Thisse (1979) and Shaked and Sutton (1982). Katz (1984) has modeled the pricing decisions of competing, multiproduct firms and demonstrates that firms may use a price-quality schedule to price discriminate when consumers have preferences over firms.

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and shown to exist even in free-entry markets (Borenstein 1985; Holmes 1989). These analyses suggest that a firm with a downward-sloping demand curve can price discriminate even when its market power over price arises only from monopolistically competitive product differentiation.

While recent theory supports the possibility of price discrimination in multifirm markets, demonstrating that discrimination explains any observed price differential has been difficult. The empirical problem is distinguishing cost-based differentials from discriminatory differentials, a problem typically compounded by inadequate cost data. This paper exploits a natural experiment in which firms differ in the ability to price discriminate but not in the cost of production. Differences in price structures across firms are then argued to be evidence of price discrimination. In particular, the paper compares the price differential between full-service and self-service gasoline at stations offering both service types (multiproduct stations) with the price differential across stations offering only full-service and stations offering only self-service (single-product stations). The intuition for this comparison is as follows: Assume that there is no difference in the cost of selling full-service or self-service gasoline caused by selling them at the same location rather than separately. Assume also that any gasoline station has some market power as a result of location and brand, and consumers differ in their willingness to pay for the additional service associated with full-service gasoline. Under these conditions, a multiproduct station will be able to price discriminate because it can set two prices. A single-product station cannot because it has only one price. A multiproduct station will choose the discriminatory prices that maximize combined profit from the sales of both service types; a single-product station will choose the price that maximizes profits from a single service type.

Variation in the ability to price discriminate implies a wider difference between full-service and self-service prices at multiproduct stations than across single-product stations. If multiproduct stations are price discriminating, the full-service price will be higher at these stations and the self-service price lower. Raising the full-service price is less costly to a multiproduct station because customers no longer willing to pay for full-service switch to self-service at the same station. At a single-product full-service station, raising the price results in a loss of customers. Lowering the self-service price is less costly at multiproduct stations because there are fewer inframarginal self-service customers than there are at single-product self-service stations. Retail price data confirm that the service price differentials do in fact differ in a way consistent with price discrimination.

Inferring price discrimination from price differentials clearly depends on cost invariance and is possible here because station-level data allow the analysis to control for potential sources of cost variation. The assumption that any cost differences based solely on collocation versus separation are small is intuitively appealing. Nonetheless, fixed or marginal costs might vary if single-product and multiproduct stations vary systematically in other station characteristics or in the market environments in which they operate. Data on station characteristics are used to control for station-level differences, and data on station location are used to control for variations in market environment. It is possible to compare price differentials at stations that are very close together (similar market environments) and have similar characteristics. The variation in price differentials predicted by the price discrimination model persists when these controls are imposed.

Price dispersion unrelated to price discrimination can arise if peak-load pricing is an equilibrium strategy. If stations are unable to adjust prices when demand changes and capacity is costly, then competitive, peak-load pricing can result in a price dispersion (weakly) consistent with that predicted by the price discrimination hypothesis. The consistency is weak because the peak-load pricing model predicts only dispersion, not the pattern that dispersion takes. Price discrimination predicts a specific pattern of price dispersion. The sharp prediction of the peak-load pricing model is equal (zero) profit per unit of capacity at all stations. Because only multiproduct stations have the ability to price discriminate, the discrimination hypothesis predicts higher profit at these stations. Data on capacity, prices, and quantities are used to estimate relative profitability, and the results are inconsistent with peak-load pricing.

Section II develops a simple model of price discrimination and characterizes the resulting price differentials and profit levels. These results are compared with the predictions of a perfectly competitive model that precludes price discrimination but may allow peak-load pricing. Section III presents the empirical results, and concluding comments are offered in Section IV.

II. A Model of Retail Pricing and Outlet Type

Gasoline stations are horizontally differentiated (by brand and location): if price and service quality are held constant, consumers prefer "nearby" stations. Because gasoline can be sold full-service or self-service, it can also be thought of as a vertically differentiated product: with proximity held constant, consumers will prefer full-service to self-service when both are offered at the same price. In general, retail prices will reflect horizontal competition as well as any price discrimination based on vertical differentiation, and a complete model would take both types of differentiation into account. Since this paper focuses on price discrimination given some amount of market power, the analysis is simplified by looking only at polar cases.

In the competitive case, there is no horizontal differentiation. In a model of spatial competition, this is equivalent to assuming that consumer transportation costs are zero. In the market power case, there is extreme horizontal differentiation so that each outlet is an effective monopoly. Again, in a spatial competition model, this is equivalent to assuming that transportation cost is zero to the closest station and infinite to any other. While neither the polar competitive nor market power case captures the nature of interfirm competition in gasoline retailing, analyzing them isolates the effects of price discrimination. If the market is competitive, there is no price discrimination. In the market power case, multiproduct stations will price discriminate while single-product stations will charge the single monopoly price for their service quality.

Pricing decisions are modeled as a short-run problem in which the structure of the retail system is exogenous. In particular, the nature of competition and the distribution of stations and station types are taken as given. Retail prices are determined in a two-stage problem. The upstream firms (refiners) first choose the terms on which the product is transferred to retail outlets. In this stage, each refiner chooses a wholesale price (w) and (perhaps station-specific) franchise fee. The optimal two-part tariff will be determined by the nature of both upstream and downstream competition, but it is not necessary to solve for the optimal tariff in order to derive predictions about relative prices and profitability. The subsequent analysis merely imposes the condition that the tariff is consistent with nonnegative outputs at all stations. It also assumes that w is not station-specific. In fact, there are posted free on board and delivered wholesale prices, and each station in the wholesale area faces the same price schedule. Discounts are sometimes offered, but not apparently on a station-specific basis (U.S. Department of Energy 1984). In the second stage, the retailer chooses a retail price for each service quality offered at her station. This choice is conditioned on the wholesale price, the nature of downstream competition, and the type of station she operates.

To simplify the discussion, the following notation is adopted. Variables indexed by f (s) refer to full-service (self-service) gasoline, and variables indexed by MP (SP) refer to multiproduct (single-product) stations. Thus p_s^{MP} is the self-service price at multiproduct stations. Because the model is generally applicable to any product that has a high-quality and a low-quality version, it is sometimes simpler to refer to self-service as low-quality and full-service as high-quality.

A. *Demand and Cost*

Market demand is modeled following Jaskold-Gabszewicz and Thisse (1979). Each consumer buys no more than one unit of gasoline per period and has a utility function separable in income and gasoline consumption. Consumers have identical preferences but different incomes. Because higher-income individuals have a lower marginal utility of income, they have a higher willingness to pay for service. Preferences can therefore be represented by

$$U = \begin{cases} V(g)(t - p_g) & \text{if she consumes one unit of service level } g \\ V(o)t & \text{if she does not purchase,} \end{cases}$$

where g is full-service (f) or self-service (s), $V(f) > V(s) > V(o) > 0$, and t is the consumer's type. Type is assumed to be uniformly distributed on [0, 1], with higher values of t corresponding to higher levels of income. When there is only one service type available, all consumers who prefer consumption of the available quality to no purchase at the prevailing price will buy. Demand for this quality is given by

$$D(p_g) = 1 - \frac{V(g)p_g}{V(g) - V(o)}. \tag{1}$$

When both qualities are available, all consumers who prefer one quality to the other and to no purchase at the prevailing prices will buy that quality. Demand for each quality is given by

$$\begin{aligned} D_f(p_f, p_s) &= 1 - \frac{V(f)p_f}{V(f) - V(s)} + \frac{V(s)p_s}{V(f) - V(s)}, \\ D_s(p_s, p_f) &= \frac{V(f)p_f}{V(f) - V(s)} - \frac{V(s)[V(f) - V(o)]p_s}{[V(f) - V(s)][V(s) - V(o)]}. \end{aligned} \tag{2}$$

Because quality is produced at the retail level, upstream production costs are service invariant and can be set equal to zero without loss of generality. Downstream, full-service typically involves an increase in marginal cost because it requires more labor and (perhaps) more highly skilled labor. For simplicity, marginal retailing costs are assumed to be constant, the cost of self-service is set equal to zero, and the increment to marginal cost for producing high quality is $\alpha \geq 0$. Total marginal cost at the retail level, then, is w for self-service and $w + \alpha$ for full-service. Marginal cost is assumed to be invariant to station type. That is, the cost of full-service (self-service) is the same at single-product and multiproduct dealers. This assumption is essential to the empirical power of the model and is discussed at length in Section III.

Fixed costs primarily reflect the value of the land, building, tanks, and pumps. It is assumed that equilibrium variable profit is high enough to cover any fixed cost. The cost of capacity will be important in analyzing the competitive case and is discussed further in that context. In the market power case, fixed cost will not affect the retailer's price choice as long as profit is strictly positive.

B. The Market Power Case

If retailers have market power, equilibrium prices will depend on the station type. For a single-product station, profit is maximized by solving

$$\max_{p_f} \Pi_f^{\mathrm{SP}} = (p_f - w - \alpha)D(p_f) \tag{3}$$

if the station offers full-service or

$$\max_{p_s} \Pi_s^{\mathrm{SP}} = (p_s - w)D(p_s) \tag{4}$$

if the station offers self-service. The profit-maximizing prices are

$$\begin{aligned} p_f^{\mathrm{SP}} &= \frac{V(f) - V(o)}{2V(f)} + \frac{w + \alpha}{2}, \\ p_s^{\mathrm{SP}} &= \frac{V(s) - V(o)}{2V(s)} + \frac{w}{2}. \end{aligned} \tag{5}$$

The analogous problem for a multiproduct retailer is

$$\max_{p_f, p_s} \Pi^{\mathrm{MP}} = (p_f - \alpha - w)D_f(p_f, p_s) + (p_s - w)D_s(p_s, p_f). \tag{6}$$

The profit-maximizing prices are

$$\begin{aligned} p_s^{\mathrm{MP}} &= \frac{[V(f) + V(s)][V(s) - V(o)]}{\delta} + \frac{2wV(f)V(s)}{\delta} \\ &\quad + \frac{\alpha V(f)[V(s) - V(o)]}{\delta}, \\ p_f^{\mathrm{MP}} &= \frac{2V(s)[V(f) - V(o)]}{\delta} + \frac{wV(s)[V(f) + V(s)]}{\delta} \\ &\quad + \frac{\alpha V(s)[2V(f) - V(o) + V(s)]}{\delta}, \end{aligned} \tag{7}$$

where $\delta = 3V(f)V(s) + V(f)V(o) + V(s)^2 - V(s)V(o)$.

Given the prices defined by (5) and (7), calculating price differentials is straightforward. Let the differentials between full- and self-service prices be denoted Δ_{MP} and Δ_{SP}, and the difference in these differentials be denoted as Δ:

$$\begin{aligned} \Delta_{MP} &\equiv p_f^{MP} - p_s^{MP}, \\ \Delta_{SP} &\equiv p_f^{SP} - p_s^{SP}, \\ \Delta &\equiv \Delta_{MP} - \Delta_{SP}. \end{aligned} \tag{8}$$

It is clear from the price equations that these differentials are functions of both α and w as well as the taste parameters. As a result, it is not possible to sign these expressions for all values of α and w. It is possible, however, to determine the signs for all values of w and α that are consistent with nonnegative equilibrium quantities. When α and w satisfy these feasibility constraints (described in the Appendix), it is easy to show that all three differentials are positive except at a single point in (α, w) space.[2]

Since service has been modeled as a vertically differentiated good and the cost of high quality is nonnegative, it is not surprising that the full-service price is higher than the self-service price at both single-product and multiproduct stations. The sign of Δ is less obvious and can best be understood by first identifying its components. A larger differential at multiproduct stations can be the result of a higher price for full-service, a lower price for self-service, or both. When the same feasibility constraints are imposed, it is possible to show that the self-service price is not higher and the full-service price is not lower:

$$\begin{aligned} \Delta_f &\equiv p_f^{MP} - p_f^{SP} \geq 0, \\ \Delta_s &\equiv p_s^{MP} - p_s^{SP} \leq 0. \end{aligned} \tag{9}$$

The inequalities will be strict unless a feasibility constraint binds, and one must be strict.

The intuition for the lower self-service and higher full-service price at multiproduct stations is more easily understood if w and α are set equal to zero, a simplification that does not change the underlying effects. Each type of single-product station will increase its price until the cost of losing the marginal consumer equals the benefit from

[2] As shown in the Appendix, there is a kink in the constraints defining feasible α and w at $\hat{\alpha}$. At that point, $\Delta = 0$. The restrictions on α and w define the range of values that are consistent with dealer rationality in the sense that they allow both single-product and multiproduct dealers to make nonnegative sales at equilibrium prices for all qualities offered. These restrictions must also be satisfied if the model is to have empirical content; all stations do in fact sell positive quantities at each service level they offer.

charging a higher price to the inframarginal consumers. With $w = \alpha = 0$, each station will sell to half the consumers in its market. This is just the familiar result for a monopolist facing a linear demand curve. Now suppose that a multiproduct station were to charge these prices. With both qualities available, these prices would lead to no self-service sales and full-service sales to half the market.[3] Consider a small reduction in the full-service price. This will have the same effect at the multiproduct station that it has at the single-product station: since it is not optimal for the single-product station, it cannot be optimal for the multiproduct station. Consider a small increase in the full-service price. This has the same inframarginal effect at both station types. The marginal effect, however, is lower for the multiproduct station because the marginal consumer moves to self-service rather than to no purchase. The multiproduct station therefore has an incentive to increase the full-service price.

With regard to the self-service differential, a price increase at the multiproduct station has no effect at all. A price decrease has two marginal effects at a multiproduct station. First, some consumers switch from no purchase to a self-service purchase. This is the same as the marginal effect at single-product stations. Second, some customers switch from full-service to self-service. The composite marginal effect is still positive at the single-product monopoly prices but is lower than the marginal gain at single-product stations. However, there is no inframarginal loss at the multiproduct station because no self-service sales were made before the price decrease. The multiproduct station therefore has an incentive to reduce the self-service price.

In summary, the price discrimination model predicts that, compared to single-product prices, the multiproduct self-service price will be no higher ($\Delta_s \leq 0$) and the multiproduct full-service price will be no lower ($\Delta_f \geq 0$). As a result, the difference in differentials will be positive ($\Delta > 0$). It also is clear that if the stations face the same demand, multiproduct stations will be more profitable than either type of single-product station. For low values of α, full-service single-product stations will be more profitable than single-product self-service because consumers prefer high quality to low quality at equal prices. However, for large values of α, self-service is more profitable. When α is large, the higher marginal cost more than offsets the greater demand for high quality.

[3] More precisely, each consumer of type $t < \frac{1}{2}$ would prefer no purchase to either quality. Each consumer of type $t > \frac{1}{2}$ would prefer full-service to self-service and to no purchase. The consumer at $t = \frac{1}{2}$ is indifferent among all three options.

C. *The Competitive Case*

If the market is competitive, any price differentials must just cover differences in cost. If there were no fixed cost, perfect competition would require prices equal to marginal cost at every station. When marginal costs do not vary by station type, this implies $\Delta_f = \Delta_s = \Delta = 0$. In the more realistic case of positive fixed costs, the competitive case is a free-entry market in which firms remain horizontally undifferentiated (no market power). Prices must remain high enough to cover fixed cost, but these three differentials will remain equal to zero as long as fixed costs do not vary by station type. In addition, each type of station will earn zero profit. This case provides clearly conflicting predictions with respect to both price structure and profits compared with the price discrimination model.

If intertemporal fluctuations in demand are an important determinant of pricing behavior in retail gasoline markets, a better null hypothesis might come from a peak-load pricing model. The demand for gasoline clearly varies over the course of a day. At peak periods, it is not unusual to observe congestion at gasoline pumps; stations do not adjust prices to clear the market. When prices do not adjust to demand fluctuations and consumers buy from the lowest-price, uncongested station, the equilibrium price distribution will involve dispersion and, in expectation, all firms will earn zero profit.[4] A high-price station will sell at capacity only rarely, and a lower-price station will sell at capacity more often. The high-price station is charging a peak-load price. In equilibrium, each station must make zero profit on average or it will be profitable for some firm to add capacity.

Under this scenario, it is possible that the multiproduct full-service price is a peak-load price. This is not a necessary result: it is also possible for a single-product station to be a high-price station. There is nothing special about collocation in this model: multiproduct full-service and self-service capacities will each be priced to cover service-specific cost. Because this model makes no prediction about which prices will be relatively high, it cannot be tested using price differentials. The theory does, however, make a clear prediction about profit that is distinct from the prediction of the price discrimination model. If the observed dispersion arises from peak-load pricing by competitive firms, each unit of capacity will generate just enough revenue to cover its cost.

Consider a station with a capacity of k units costing r per unit.

[4] This result has been demonstrated by Butters (1977) in a model in which firms choose price and advertising. For a simple application of this approach to a peak-load pricing problem, see Rotemberg and Summers (1988).

Then, the following conditions must be satisfied in equilibrium:

$$q_s^{\mathrm{SP}}(p_s^{\mathrm{SP}} - c) - rk_s^{\mathrm{SP}} = 0, \tag{10a}$$

$$q_f^{\mathrm{SP}}(p_f^{\mathrm{SP}} - c - \alpha) - rk_f^{\mathrm{SP}} = 0, \tag{10b}$$

$$q_s^{\mathrm{MP}}(p_s^{\mathrm{MP}} - c) - rk_s^{\mathrm{MP}} = 0, \tag{10c}$$

$$q_f^{\mathrm{MP}}(p_f^{\mathrm{MP}} - c - \alpha) - rk_f^{\mathrm{MP}} = 0, \tag{10d}$$

where c is the marginal cost of self-service. If these constraints are not satisfied, the price differentials cannot be explained by peak-load pricing.

III. Evidence from Retail Gasoline Markets

The data used to test the price discrimination hypothesis are a cross section of retail prices and characteristics for all 1,527 stations in a four-county area in eastern Massachusetts.[5] Data on station location (street addresses and cross streets), ancillary services, gasoline brand, station capacity, and service level (full or self) are included. Although the data are treated as a cross section, data collection occurred over a 12-week period in early 1987, during which the wholesale prices of refined petroleum products were rising slowly. To adjust for wholesale price increases, the retail prices have been indexed using weekly free on board wholesale price data for the Boston area.[6] Retail prices observed in any given week are indexed by the wholesale price reported at the end of the preceding week. Full-service and self-service prices (and any cash discounts) are reported for each gasoline grade. The prices used in the analysis are the minimum price at each station for the specified gasoline grade and service quality. The analysis focuses on branded gasoline: Shell, Exxon, Amoco, Gulf, Mobil, Citgo, Texaco, Sunoco, and Chevron in the Boston area. Unbranded gasoline is gasoline not associated with a major refiner (e.g., Merit, Global, Angelo's, Stop-N-Go) and sells at a retail discount from branded prices.

As shown in table 1, approximately two-thirds of the stations are single-product full-service, with the remaining stations split fairly evenly between multiproduct and single-product self-service. This distribution is unusual: nationally the proportion of full-service sta-

[5] The data set covers Norfolk, Suffolk, Middlesex, and Essex counties and includes the cities of Boston and Cambridge as well as outlying suburban areas, extending north to New Hampshire, south to Rhode Island, and approximately 25 miles west of Boston Harbor.

[6] The station-level data were collected by Lundberg Surveys, Inc. The wholesale price data come from the Oil Price Information Service.

TABLE 1

BRANDED STATION CHARACTERISTICS

	Single-Product Full-Service	Single-Product Self-Service	Multiproduct
Number of stations	1,006	282	239
Number of branded stations	791	136	232
Repair service (%)	89.3	32.4	90.1
Convenience store (%)	3.7	41.9	5.2
Remodeled (%)	44.2	72.8	74.1
Average islands	1.29	2.25	2.11
	(.49)	(1.81)	(.49)
Average fueling places	3.60	5.83	5.51
	(1.64)	(2.09)	(1.89)
Full-service	...	...	2.63
			(1.02)
Self-service	...	...	2.88
			(1.16)
Average monthly sales	48.90	96.91	90.18
(thousands of gallons)	(29.93)	(42.49)	(40.33)
Average capacity utilization	14.50	17.64	17.45
(thousands of gallons)	(8.15)	(7.97)	(7.94)

NOTE.—Standard deviations are in parentheses.

tions has declined to less than one-third of all stations by 1987 (*National Petroleum News—Factbook Issue,* 1988). For unknown reasons, the retail system has changed more slowly in the Boston area than in the United States as a whole. Approximately three-quarters of the stations carry branded gasoline. Compared with branded stations, unbranded stations are more likely to be self-service outlets and much less likely to be multiproduct outlets. Historically, unbranded gasoline has gained market share by offering low service and low price; self-service gasoline was introduced by unbranded retailers. In contrast, the branded networks were built to emphasize full-service gasoline sales. While self-service has become the dominant mode for all gasoline sales, the characteristics of the branded and unbranded networks reflect their distinct histories.

Of the stations offering full-service, 90 percent also offer automotive repair service, compared to about one-third of the self-service single-product stations. Self-service only stations are more likely to have convenience stores, a configuration that is uncommon for stations offering full-service. The data identify stations that have been remodeled within the 3 years prior to data collection,[7] and new capital investment appears to be more likely at multiproduct and single-

[7] The data record remodeling but not what has been done. Remodeling can mean anything from complete rebuilding to adding a canopy.

product self-service than at full-service only stations. This is consistent with the national trend toward abandoning full-service stations in favor of multiproduct or self-service stations. Full-service stations also are noticeably smaller than other stations: they have fewer gasoline islands and can serve fewer cars simultaneously (simultaneous service capacity is reported as "fueling places" in table 1). Total output and output per fueling place ("capacity utilization") also are lower at full-service stations.[8]

A. *Cost Differences*

Interpreting variations in price as evidence of price discrimination requires that the product be produced at the same cost. In many ways, gasoline retailing at stations of different types constitutes a natural experiment holding constant critical cost and product elements. Because the data pertain to stations in the same geographic area, the wholesale price of gasoline and the price of labor will be invariant to station type. Retailing technology would also seem to be type invariant. Nonetheless, it is in principle possible that cost variation across stations might induce price variation unrelated to price discrimination. The data contain no direct cost information, but do contain information on scale and product mix that might suggest cost differences. Here, I argue that these data suggest that any differences would bias the results against a finding of price discrimination. The analysis presented in the following subsection supports the claim that cost variations associated with these variables cannot explain the observed price differentials.

Marginal costs might differ if wholesale volume discounts, differences in capital productivity, or unobserved service variation is important. There is some evidence that refiners use nonlinear wholesale pricing (U.S. Department of Energy 1984). If this practice is widespread, high-volume stations will have lower marginal cost. As is evident in table 1, full-service outlets typically are the low-volume stations. Stations with newer, more efficient capital (e.g., faster pumps or electronic control equipment) might have lower marginal cost. A lower proportion of full-service only stations have been remodeled recently, suggesting that they have older capital on average than the other stations. If volume discounts or capital differences are important, the data suggest that the marginal cost of full-service will be lower at multiproduct stations.

[8] Because gasoline islands can vary in size, number of fueling places is a better capacity measure. Fueling places also are broken out by service level at multiproduct stations. For these reasons, number of fueling places is the capacity measure used in the subsequent analysis.

The marginal cost of high quality might be higher at multiproduct stations if quality is different in unobserved ways. Suppose that consumers differ in their willingness to pay for driveway service (checking the oil, tire pressure, etc.). If customers with relatively high demand for driveway service are buying at multiproduct stations, the cost of full-service might be higher there,[9] warranting a higher price. There is no reason, however, for the high-demand consumers to choose a high price when a lower price is available. In the absence of local market power, there is no way to separate high- and low-demand customers by station type. If the stations have market power, the multiproduct stations will price discriminate. It is then possible that the multiproduct station would have a higher marginal cost because the high, discriminatory, price has produced a customer population with a higher average demand for driveway service. Even this argument, however, is somewhat strained. Gasoline pumping and driveway service are bundled. As the price of the bundle rises, fewer consumers will purchase it. Once it is purchased, the entire bundle will be consumed. Full-service customers with different reservation prices for the bundle will consume different levels of driveway service only if their demands differ when driveway service is free. In any case, any cost difference is the result of price discrimination.

If fixed costs differ by station type and must be covered with gasoline revenue, price differences could be cost-based even if marginal costs are type invariant. In particular, if there are station-level fixed costs, prices may be higher at smaller-volume stations, implying higher prices at full-service single-product stations. If there are scale economies specific to service quality, the capacity data suggest a possible loss of scale economies at multiproduct stations. Although these stations have a total capacity similar to self-service stations, capacity per service type is much closer to that of the typical full-service station. Any loss of service-specific scale economies at multiproduct stations, then, will be more severe for self-service gasoline, suggesting that the service cost differential should be lower at these stations.

Finally, economies of scope could affect pricing. There may be scope economies in combining full-service and auto repair or self-service and convenience shopping. The observed product mix distribution indicates that full-service gasoline is sold in similar environments, but self-service gasoline is not. Thus the cost of full-service should be type invariant, but self-service could be more costly at multiproduct stations.

[9] Note, however, that checking oil is necessary for selling oil; more intense service may generate more revenue per customer than less intense service. Indeed, owners of full-service stations have resisted refiner attempts to shift them to self-service because full-service generates sales of nongasoline service and products.

Taken together, these factors suggest that any cost variations should lead to higher, not lower, price differentials at single-product stations. If the cost differential is larger at single-product stations *and* multiproduct stations price discriminate, the single-product price differential could be smaller (if the price discrimination effect dominates) or larger (if the cost effect dominates). Cost variation could disguise price discrimination but cannot reasonably be expected to mimic it. Testing for price discrimination on the basis of the sign of Δ can lead to false negatives but not false positives.

B. *Price Differential Results*

The price differential tests focus on signing $\Delta_f \equiv p_f^{\mathrm{MP}} - p_f^{\mathrm{SP}}$, $\Delta_s \equiv p_s^{\mathrm{MP}} - p_s^{\mathrm{SP}}$, and $\Delta \equiv \Delta_f - \Delta_s$ while controlling for differences in station characteristics and market environment that might affect the price structure. Prices at station i of type k (k = MP or SP) for gasoline supplied with service quality g (g = full or self) in market j can be represented by

$$p_{ikgj} = \beta_0 + \beta_1 D_g + \beta_2 D_k + \beta_3 D_k D_g + \gamma_1 M_j + \gamma_2 M_j D_k + \phi \mathbf{X}_{ikg} + \epsilon_{ijkg}, \tag{11}$$

where D_g is a dummy variable for service quality set equal to one for full-service prices, and D_k is a dummy variable for station type set equal to one for prices at multiproduct stations; $\mathbf{X}$ is a vector of station characteristics that may vary by service level and station type; and M is a market fixed effect included to account for price effects from local, unobserved variations in supply or demand conditions. By construction, β_0 is the mean price for self-service gasoline at single-product stations, β_1 is the average increment to this price charged for full-service at single-product stations ($\overline{\Delta}_{\mathrm{SP}}$), and β_2 is the average increment charged for self-service at multiproduct stations ($\overline{\Delta}_s$). The average full-service differential ($\overline{\Delta}_f$) is $\beta_2 + \beta_3$, and the average difference in differentials ($\overline{\Delta}$) is β_3. Without peak-load pricing, the competitive model predicts that $\overline{\Delta}$, $\overline{\Delta}_f$, and $\overline{\Delta}_s$ will be zero, while price discrimination at multiproduct stations implies that $\overline{\Delta}$ will be positive, $\overline{\Delta}_f$ will be nonnegative, $\overline{\Delta}_s$ will be nonpositive, and either $\overline{\Delta}_f$ or $\overline{\Delta}_s$ must be nonzero.

The vector of station characteristics ($\mathbf{X}$) includes variables that might be related to cost or demand:[10] The variable CSTORE is a

[10] To test for price discrimination, it is important to account for any differences in cost. If stations have some market power, differences in demand unrelated to service quality may also affect prices. It is possible, e.g., that consumers are willing to pay more for gasoline if they can also purchase convenience store items at the same location.

dummy variable for a convenience store, and REPAIR is a dummy variable for automotive repair service. Capacity is represented by the number of fueling places and is station type specific to allow for differences in scale effects. The variable SPFCAP (SPSCAP) is the number of fueling places at single-product full-service (self-service) stations, and MPCAP is the number of full- and self-service fueling places at multiproduct stations. The variable UNBRANDED is a dummy variable set equal to one if the price comes from an unbranded station. Some of the prices recorded as self-service are actually for mini-service, in which a station employee pumps the gasoline but will not perform any of the other services associated with full-service (cleaning windows, checking fluid levels, etc.). Because mini-service is more labor intensive than self-service, it may be more costly. Six percent of the branded stations classified as self-service and 23 percent of the stations classified as multiproduct offered mini-service rather than self-service. The variable MINI is a dummy variable for mini-service at self-service pumps. Finally, NEW is a dummy variable for stations that have been remodeled in the 3 years prior to observation.

If the unobserved market effects are zero or are uncorrelated with the other explanatory variables, an unbiased estimate of the remaining parameters can be obtained by estimating

$$p_{ikgj} = \beta_0 + \beta_1 D_g + \beta_2 D_k + \beta_3 D_k D_g + \phi \mathbf{X}_{ikg} + \mu_{ijkg}. \qquad (11')$$

The ordinary least squares estimates of (11′) appear in table 2 for three grades of gasoline: regular leaded (89 octane), regular unleaded (87 octane), and premium unleaded (92 octane). To facilitate interpretation, the parameters associated with the station type and service-level dummy variables appear in parentheses. Thus, for example, the coefficient on the $D_g D_k$ interaction is an estimate of Δ. Because the number of observations is the number of prices, multiproduct stations will have two observations for each grade. A few stations do not carry all three grades. In addition, some missing data for NEW have reduced the number of usable observations.

The coefficient estimates are consistent with the price discrimination hypothesis and inconsistent with cost-driven differentials. On average, the price differential at multiproduct stations is 9¢–11¢ higher than the differential across single-product stations. The higher differential comes largely from higher full-service prices. The mean self-service differential ($\overline{\Delta}_s$) indicates that multiproduct stations charge 2¢–3¢ less for self-service unleaded gasoline, but this differential cannot be statistically distinguished from zero. The mean full-service differential ($\overline{\Delta} + \overline{\Delta}_s$), however, is quite large, ranging from 7¢ to 9¢. Multiproduct stations charge a full-service markup ($\overline{\Delta}$ +

TABLE 2

PRICE DIFFERENTIALS BY GRADE

	Regular Leaded	Regular Unleaded	Premium Unleaded
Constant	75.47	83.02	97.18
	(1.36)	(1.48)	(1.59)
D_g ($\bar{\Delta}_{SP}$)	6.89	7.64	8.04
	(1.45)	(1.56)	(1.68)
D_n ($\bar{\Delta}_s$)	.00	−2.89	−2.03
	(1.67)	(1.79)	(1.90)
D_gD_n ($\bar{\Delta}$)	9.39	11.23	9.22
	(1.58)	(1.69)	(1.82)
UNBRANDED	−1.97	−4.65	−6.44
	(.55)	(.53)	(.58)
MINI	.19	2.96	2.88
	(.90)	(1.01)	(1.07)
SPFCAP	−.89	−.72	−.70
	(.16)	(.16)	(.17)
SPSCAP	−.21	−.28	−.17
	(.18)	(.20)	(.21)
MPCAP	−.21	.25	.16
	(.18)	(.18)	(.19)
REPAIR	1.80	.38	.11
	(.55)	(.59)	(.63)
CSTORE	1.43	.68	−.57
	(.70)	(.76)	(.81)
NEW	−1.40	−1.66	−1.64
	(.39)	(.41)	(.44)
STATIONS	1,052	1,291	1,237
R^2	.46	.45	.42

NOTE.—Standard errors are in parentheses.

$\bar{\Delta}_{SP}$) of 16¢–19¢ over their self-service price; full-service single-product stations charge 7¢–8¢ more than single-product self-service stations.

As expected, unbranded gasoline is sold at a significantly lower price than branded gasoline: the markup for branding is 2¢–6¢ a gallon. Mini-service increases the price of self-service gasoline by 3¢ a gallon for unleaded gasoline. Recently remodeled stations appear to have somewhat lower prices, suggesting that newer stations may be more cost efficient. Capacity has no effect at multiproduct or self-service stations but reduces prices slightly at full-service stations. This is consistent with the exhaustion of station-level economies of scale at the average self-service and multiproduct station, but not at the average full-service station. There is no significant effect from having repair service or a convenience store except for leaded gasoline: stations offering these services charge somewhat higher prices for leaded gas. In general, the price effects for leaded gas are noticeably different from those for unleaded gas. This might be related to the declining demand for leaded gasoline. Only older cars use leaded, and it may be priced for a very different market.[11]

The results in table 2 are robust to a variety of tests for potentially confounding effects. Some of the price differences, for example, could reflect variations in wholesale pricing or distribution strategies of upstream firms. To test for brand-specific effects, (11′) was run with brand fixed effects and, where possible, with brand-specific intercepts and slopes.[12] Although some of the brand fixed effects were significant and the magnitude of some coefficients varied slightly across brands, the (unreported) results confirm the findings reported in table 2. Prices have been indexed to account for changes in the wholesale prices over the data collection period, but it is possible that temporal changes in retail margins are biasing the results. Estimating (11′) for each week of observations produces (unreported) estimates very similar to those reported in table 2. Restricting the analysis to stations with the same capacities also has no important effect.

The error term in the regressions reported in table 2 includes the market effects and therefore incorporates any unobserved, local differences in supply or demand facing the stations. The volume of traffic and the taste distribution of potential customers may vary across the surveyed area. It is also possible that variations in land values are important or that there are variations in delivery charges. If the distribution of station types also varies across localities, unobserved local characteristics may bias the results from estimating (11′).

These unobserved effects can be removed by constructing an average price for gasoline of quality g sold at a station of type k for each market and differencing by service quality. This leads to two equations for each market of the form

$$\overline{\Delta}_{gj} = \overline{p}_{1gj} - \overline{p}_{0gj} = \Theta_j + \phi(\overline{\mathbf{X}}_{1gj} - \overline{\mathbf{X}}_{0gj}) + \overline{\mu}_{1gj} - \overline{\mu}_{0gj}, \qquad (12)$$

where $\overline{p}_{1gj}$ ($\overline{p}_{0gj}$) is the average price for gasoline of quality g at multiproduct (single-product) stations in area j. Differencing eliminates the local effects common to the stations in market j. The remaining problem is to define market j.

The objective of market definition in this context is to identify a group of stations that can reasonably be expected to face common demand and supply conditions. Note that this has nothing to do with

[11] Some major refiners seem to believe that leaded gasoline prices are set not to sell leaded gasoline, for which demand is quite small, but to signal to buyers of unleaded that prices are low. Since all prices are posted, it is not clear why this signal would work, but private conversations with refiners indicate that they believe it works. For an analysis of unleaded vs. leaded prices, see Borenstein (1989).

[12] Amoco and Chevron have too few stations to estimate (11′).

defining a "market" in the usual industrial organization sense. It does not matter, for example, whether there are stations not included in the identified group that compete with the stations included in the group. In this limited sense, markets can be defined by proximity: stations within a specified Cartesian distance are said to be in the same market. Since there is no a priori rule for how large these areas can be before demand or supply heterogeneity becomes important, the analysis uses several different levels of proximity.

Finally, there is an issue about whether proximity alone implies common demand and supply conditions. Consider a town with one major street. All stations within x miles of a station on the main street may include stations on side streets—where the traffic volume and land values may be very different—as well as other stations on the main street. In this case, it might be preferable to limit the market definition to stations within x miles *and* on the main street. In contrast, if a town has two major intersecting streets, an algorithm that picks up stations on both streets might be appropriate. The analysis below uses both definitions. To implement the second definition, the analysis is limited to stations on numbered routes.

Under the first definition, the analysis begins with 1,489 stations—1,133 of which are branded stations—for which street addresses have been converted to Cartesian coordinates.[13] Among these are 227 branded multiproduct stations, each of which becomes the center for a local area j. For each multiproduct station, all branded stations within a radius of x miles are identified, the average price for each type and service ($\bar{p}_{kgj}$) is calculated, and these averages are used to construct $\overline{\Delta}_{gj}$. For $\overline{\Delta}_{gj}$ to be nonmissing, at least one branded, single-product station selling gasoline of quality g must be in area j. As a result, the number of markets is less than the number of multiproduct stations. This is particularly true for the self-service differential because there are relatively few self-service only stations. The numbers of markets (MARKETS) and stations (STATIONS) used to estimate the coefficients in equation (12) are reported in table 3. For example, when a market is defined to be all stations within a half-mile radius of the multiproduct station, there are 54 markets with at least one single-product self-service station, and these 54 markets contain 106 branded multiproduct and self-service stations. The procedure changes in an obvious way when the analysis is restricted to stations on the same numbered route. There are 775 stations on numbered routes, of which 597 are branded and 135 are branded multiproduct stations.

[13] Thirty-eight stations have been dropped because they are in geographically anomalous areas. For example, stations on narrow peninsulas jutting into Boston Harbor have been dropped.

TABLE 3

AREA REGRESSIONS

Dependent Variable	.5-Mile Radius $\bar{\Delta}_{fj}$	.5-Mile Radius $\bar{\Delta}_{sj}$	1-Mile Radius $\bar{\Delta}_{fj}$	1-Mile Radius $\bar{\Delta}_{sj}$	1.5-Mile Radius $\bar{\Delta}_{fj}$	1.5-Mile Radius $\bar{\Delta}_{sj}$	2-Mile Radius $\bar{\Delta}_{fj}$	2-Mile Radius $\bar{\Delta}_{sj}$
	All Branded Stations							
Constant	11.44	−1.43	13.09	−.63	12.51	−.15	10.90	−.29
	(1.64)	(1.00)	(1.11)	(.73)	(.91)	(.65)	(.82)	(.77)
Capacity	.21	−.29	−.47	−.49	−.52	−.27	−.33	−.25
	(.57)	(.40)	(.39)	(.29)	(.32)	(.26)	(.34)	(.37)
NEW	−1.81	−1.89	−2.61	−.18	−1.12	.22	2.82	−1.11
	(1.88)	(1.79)	(1.27)	(1.30)	(1.04)	(1.16)	(1.32)	(1.60)
MINI	...	6.19	...	6.68	...	5.44	...	6.80
		(2.24)		(1.64)		(1.46)		(2.44)
STATIONS	297	106	547	191	759	251	844	306
MARKETS	124	54	173	97	204	134	217	172
	Branded Stations on Same Route							
Constant	12.81	−3.29	13.21	−3.14	13.62	−1.95	13.66	−1.70
	(2.57)	(1.34)	(2.00)	(1.35)	(1.73)	(1.33)	(1.50)	(1.13)
Capacity	.27	−.61	.56	−.58	−.09	−.36	−.86	−.45
	(.95)	(.56)	(.72)	(.60)	(.62)	(.54)	(.53)	(.46)
NEW	−1.37	−5.31	−4.33	−3.23	−3.21	−2.81	−.32	−3.42
	(2.93)	(2.35)	(2.91)	(2.45)	(2.50)	(2.52)	(2.41)	(2.20)
MINI	...	7.59	...	7.75	...	8.85	...	9.49
		(2.47)		(3.04)		(3.25)		(3.03)
STATIONS	123	51	201	74	260	88	302	102
MARKETS	56	25	81	33	96	43	106	50

NOTE.—Standard errors are in parentheses.

The analysis is limited to prices at branded stations; the presence of unbranded stations in a market is treated as part of the common supply environment removed by differencing. Results are reported only for regular unleaded prices but are not substantively changed when other prices are used. The convenience store and automotive repair variables have been dropped from the estimating equations. In unreported results, the coefficients on these variables were unstable and did not substantively affect the price differential estimates. The capacity, remodeling, and mini-service variables all had a significant effect in the table 2 regression and have therefore been retained in estimating equation (12).

Table 3 presents weighted least-squares estimates of the mean values of Δ_f and Δ_s for each market definition. As is clear from equation (12), the means are estimated from within-market averages. These averages have been weighted to reflect the underlying number of observations, and the resulting error covariance matrix is homoskedastic. Because the underlying data are averages and a given station can contribute to the market average for more than one market, the errors in equation (12) are not independent.[14] The duplications are identifiable, however, and the exact error covariance matrix can be constructed. This matrix has been used to estimate the standard errors in table 3.

When markets are defined to include all stations within a specified radius, the results of table 2 are confirmed. Even for very tightly defined markets, the average multiproduct full-service price is 11¢–13¢ higher than the single-product full-service price. Indeed, the estimate of Δ_f is slightly higher here than in table 2. As before, the mean self-service differential is consistently negative but cannot be distinguished from zero.

The full-service results are very similar when the market definition is tightened to nearby stations on the same route. For the first time, however, the negative self-service differential can be bounded away from zero for the narrowest market definitions. A plausible interpretation is that the self-service differential is indeed negative but close enough to zero to be masked by market heterogeneity unless markets are very tightly defined. Markets containing both multiproduct and self-service stations are relatively rare and might reasonably be rather different from the average locality in the sample area.

The local market results indicate that the price differential effects do not arise from variation in demand or supply conditions that are correlated with the distribution of station types. They do not provide information about how price levels or differentials are affected by changes in station density. Few of the stations in the overall sample are isolated from competitors. Of the multiproduct stations, 80 percent have some branded competitor within a half-mile radius, and 74 (58) percent have a branded competitor offering full-service (self-service) within a half-mile radius. Among the multiproduct stations located on a numbered route, 73 percent have a branded competitor within a half mile and on the same route, and 66 (55) percent have a branded competitor offering full-service (self-service) within a half mile and on the same route. The results in table 2 indicate that price variation can persist in markets with multiple firms; the new information in table 3 is that the variation is not a spurious effect of station distribution.

[14] For example, if two multiproduct stations are within half a mile of each other, each station will contribute to the mean multiproduct prices calculated for the two markets. Further, their markets will probably include some of the same single-product stations. The errors for these two markets will not be independent.

C. *Relative Profits*

Testing the peak-load pricing hypothesis requires checking the constraints in equations (10a)–(10d). While all the retail prices, station outputs, and capacity (fueling places) are known, there are four unobserved parameters in the constraints defined by (10): α, c, q_f^{MP}, and q_s^{MP}. These parameters can be estimated by imposing the cross-equation restrictions. Suppose that c is known. Then r can be calculated from (10a) for each self-service single-product station. For each station, r is the cost of capacity that would just allow the station to break even. Let R_0 be the average r for these stations; R_0 can be used in (10b) to estimate α (α_0). Then, letting $q^{\mathrm{MP}} = q_f^{\mathrm{MP}} + q_s^{\mathrm{MP}}$, we can rewrite (10c) and (10d) as

$$(1 - \lambda)q^{\mathrm{MP}}(p_s^{\mathrm{MP}} - c) - rk_s^{\mathrm{MP}} = 0,$$

$$\lambda q^{\mathrm{MP}}(p_f^{\mathrm{MP}} - c - \alpha) - rk_f^{\mathrm{MP}} = 0,$$

where $0 \le \lambda \le 1$. Substituting α_0 for α and imposing the cross-equation equality yield an estimate of λ for each multiproduct station. The term λ is the share of total output that must be allocated to full-service at a particular multiproduct station if $\alpha = \alpha_0$ and both full- and self-service are to generate the same variable profit (revenue net of marginal cost) per unit of capacity. With an estimate of λ for each multiproduct station, (10c) or (10d) can be used to calculate the implied cost of capital that just allows the station to break even. Then if the peak-load pricing model is a good descriptor of pricing behavior in this market, the average cost of capital at multiproduct stations (R_1) should equal the average cost of capital at single-product self-service stations (R_0).

The common marginal cost, c, is not observed but can be proxied by the wholesale price of gasoline. The final estimation issue arises because only total volume, not volume by gasoline grade, is observed. There is a substantial difference in the markup of retail price over wholesale price across gasoline grades. The average self-service markup for premium unleaded, for example, is 40¢ compared to 25¢ for regular unleaded. As a result, a station that sells relatively more premium gasoline will have a higher profit per gallon. There is no way to take this source of variation into account with the available data. Instead, each station is assumed to have the same grade shares. To implement the estimation, a weighted average of the retail margins for each grade was constructed; the weights are the shares of regular leaded, regular unleaded, and premium gasoline in all gasoline sold in the state (*Petroleum Marketing Monthly*).

The R_1 and R_0 estimates from this procedure are inconsistent with the peak-load pricing model. As reported in column 1 of table 4, the

TABLE 4

PEAK-LOAD PRICING PARAMETER ESTIMATES

	All Stations (1)	Four Places (2)	Six Places (3)	Eight Places (4)
R_0 ($)	5,442.77	6,824.60	5,570.72	3,855.41
	(215.90)	(408.43)	(409.58)	(214.92)
α_0 ($)	−.17	−.33	−.15	−.16
	(.28)	(1.07)	(9.10)	(4.48)
λ_1	.31	.28	.25	.33
	(.01)	(.02)	(.44)	(.20)
R_1 ($)	7,368.67	9,119.18	6,523.92	5,416.91
	(235.78)	(446.52)	(5,520.46)	(1,924.68)
$R_1 - R_0$ ($)	1,925.90	2,294.58	953.20	1,561.50
	(319.69)	(605.21)	(5,535.64)	(1,936.64)
Number of multiproduct	230	128	37	59
Number of single-product full-service	783	381	45	48
Number of single-product self-service	130	47	33	39

NOTE.—Standard errors are in parentheses.

implied monthly cost of capital is over $1,900 higher at multiproduct stations than at self-service single-product stations. Because single-product full-service stations are smaller on average, it is possible that station-level fixed costs are biasing the results. To control for this, the remaining columns report results when total capacity is held constant. In column 2, for example, the analysis is restricted to stations with four fueling places. At multiproduct stations, this means two full-service and two self-service places. The results are substantially unchanged for stations with four fueling places. For stations with eight or six fueling places, the point estimates of $R_1 - R_0$ remain positive but are imprecise and cannot be distinguished from zero. In all cases, imposing the equality across single-product stations yields an estimate of α that may be negative.

It is possible that the test rejects peak-load pricing because the retailing system is not in equilibrium. The percentage of Boston area stations that are full-service only is about twice as high as the national average. If there is too much full-service in the market, full-service will tend to be less profitable than self-service. Further, if the system is out of equilibrium, there is no reason to think that any of the equalities in (10) will hold.

IV. Concluding Comments

The results in Section III suggest that the behavior of firms in markets once viewed as "workably competitive" can diverge substantively from the competitive model. There are many gasoline stations in the Boston area, prices are posted, gasoline itself is a fairly homogeneous product, and rivals can respond quickly to price changes. Nonetheless, the price differential at multiproduct stations does not appear to be cost driven. Nor does peak-load pricing seem to be a plausible explanation for the observed price structure. Instead, gasoline stations seem to have sufficient local market power to allow multiproduct stations to price discriminate, maintaining price differentials approximately twice as large as the differential at other firms.

While the data support the price discrimination hypothesis, the test is conducted in a single geographic area with two limiting characteristics. First, the distribution of retail configurations is unusual. There is no a priori reason to believe that the unusually high proportion of full-service stations is responsible for the price structure, and casual empiricism suggests that the multiproduct differential is relatively high in other markets as well. Nonetheless, it would be interesting to test these hypotheses in a more typical environment. Second, these data pertain to a densely stationed area. With more variation in the distance between stations, it would be possible to test the effects of station density on prices, price differentials, and other parameters of the price dispersion. A richer model of price discrimination would suggest a role for station density, and a richer data set could be used to explore these issues.

Appendix

The signs of the price differentials discussed in Section II hold for all values of w and α for which profit maximization is consistent with positive quantities of all available qualities. With equation (1), demand at single-product stations will be positive if

$$p_g^{\mathrm{SP}} < \frac{V(g) - V(o)}{V(g)}.$$

With equation (2), positive demand for both qualities at multiproduct stations requires

$$p_s^{\mathrm{MP}} < \frac{[V(s) - V(o)]V(f)}{V(s)[V(f) - V(o)]} p_f,$$

$$p_f^{\mathrm{MP}} < \frac{V(f) - V(s)}{V(f)} + \frac{V(s)}{V(f)} p_s.$$

If one substitutes for the equilibrium prices defined in equations (5) and (7), these become constraints on w and α:

$$w \leq \frac{V(s) - V(o)}{V(s)}, \tag{A1}$$

$$w \leq \frac{V(f) - V(o)}{V(f)} - \alpha, \tag{A2}$$

$$w \leq \frac{[V(f) - V(o)][V(s) - V(o)]}{V(f)[V(s) + V(o)]} + \frac{\alpha[V(s) - V(o)][V(s) + V(f)]}{[V(s) + V(o)][V(f) - V(s)]}, \tag{A3}$$

$$w \leq \frac{V(s) + V(o)}{V(s)} - \frac{2V(f)\alpha}{V(f) - V(s)}. \tag{A4}$$

The conditions given in (A1) and (A2) ensure nonnegative quantities at self-service and full-service stations, respectively. Nonnegative quantities at multiproduct stations are guaranteed by (A3) and (A4). If $w \geq 0$ is also imposed, then nonnegative profit also implies an upper bound on α at full-service only and multiproduct outlets, respectively:

$$\alpha \leq \frac{V(f) - V(o)}{V(f)}, \tag{A5}$$

$$\alpha \leq \frac{[V(f) - V(s)][V(o) + V(s)]}{2V(f)V(s)}. \tag{A6}$$

Because there is a nearby substitute for each quality at multiproduct stations not present at single-product stations, the viability constraints are tighter at multiproduct stations. It can be shown that (A3) implies (A1), (A4) implies (A2), and (A6) implies (A5). Further, $\alpha \leq \hat{\alpha} \equiv \{V(o)[V(f) - V(s)]/V(f)[V(s)]\}$ implies that the low-quality constraint (A3) will bind first because consumers prefer high quality to low when prices are equal. However, as α gets larger, the relative price of the high-quality good must increase to cover the cost. For sufficiently high α, the high-quality constraint (A4) will bind first. Substituting $\hat{\alpha}$, the switching point, into (A3) or (A4) identifies the one point in (α, w) at which $\Delta = 0$.

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