Horizontal Differentiation with Differential Input Costs: Retail Prices for Milk by Fat Content

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Introduction

Differentiated products of a basic good usually have differential costs. Most studies on product differentiation with differential costs focus on the case of vertical differentiation, that is, when all consumers have the same ordinal preference ranking over attributes of differentiated products, and it is more costly to produce higher ranked products [Mussa and Rosen, Maskin and Riley, Gabszewicz and Thisse, and Shaked and Sutton (1982, 1983)]. But a similar market phenomenon, horizontal differentiation with differential costs, has not received comparable attention. For example, consider fluid milk products, which are differentiated on fat content. Consumers differ in their preferences for fat content of milk. Some consumers prefer skim or low-fat milk because they do not want to consume butterfat, while other consumers like whole milk because it tastes better and/or it is more nutritious. On the other hand, the costs of different types of milk are not the same. The cost of whole milk, which includes the most of the expensive butterfat input, is higher than the cost of low-fat or skim milk. This type of market phenomena can also be found for other goods including foods with differing sugar contents and cars with different engine sizes.

The markets for horizontally differentiated products with differential costs have special features which are quite different from those of the markets for vertically differentiated products with differential costs, such as the typical market in the Mussa-Rosen study. First, in the markets for horizontally differentiated products, the cost difference between differentiated products induces sellers to provide low-cost varieties whenever possible. While in the markets of vertically differentiated products, sellers need to consider both the cost-savings of low-cost varieties and consumers' higher willingness to pay for high-cost varieties, which are also of high quality. Second, in the markets with horizontal differentiation, consumers' disutility of consuming a type of product other than their ideal type encourages sellers to offer their ideal types of products or alternative types which are very close to the ideal types to each consumer. But, in the markets with vertical differentiation, consumers' identical ordinal preference ranking of products gives sellers an incentive to provide highly-ranked products.

Third, it is the consumers with preferences in the middle of the preference range for the differentiated product attribute that impose the largest negative externalities on a seller's ability to extract consumer surplus from other consumers in the markets with horizontal differentiation. In contrast, it is the consumers whose preferences are in the lowest range that impose the largest negative externalities in a market with vertical differentiation (Mussa and Rosen). In the markets with horizontal differentiation, the customers whose preferences are in the middle of the range are more likely to be indifferent among different varieties of the basic good than other consumers. So they are more willing to switch to another type of product if the price of one type is too high. Thus, they impose the strongest restriction on a seller's ability to extract consumer surplus.

These three features combine to make markets for horizontally differentiated products with differential costs a unique topic worth studying. We first develop a basic model to study retailers' pricing strategies and market equilibrium for two horizontally differentiated products with predetermined attributes under different competition scenarios. Xia extends the basic model to a more general setting to analyze both product introduction and price setting decisions of a monopoly seller for markets with horizontal differentiation and differential costs. We also conduct an empirical study on retail markets for fluid milk. Data on milk retail prices and costs for four California cities and five non-California cities are used to test the hypotheses derived from the conceptual model.

The Basic Model

We consider grocery retailers who sell two horizontally differentiated products of a basic good, one product with a lower cost and another product with a higher cost, in addition to a large number of other goods.[1] We use subscripts L and H to represent the low-cost and the high-cost product, respectively. We adopt the Hotelling framework to model the products' horizontally differentiated attribute and consumers' preferences. The attribute of a product is denoted as q_j, where j = L, H. We set $q_L = 0$ and $q_H = 1$ for the low-cost and the high-cost product, respectively. The unit variable procurement and selling cost of the low-cost product is $C_L = C_0$ and the unit variable procurement and selling cost of the high-cost product is $C_H = C_0 + (q_H - q_L)c = C_0 + c$, where $C_0 > 0$ and $c > 0$. So C_0 is the common cost component of the low-cost and the high-cost product.

Consumers are heterogeneous in terms of their preferences for the differentiated attribute of the good. We assume that consumers' tastes for the attribute, θ, are uniformly distributed over the range, [0, 1]. A consumer's utility derived from buying one unit of product j is $U(\theta, q_j, P_j) = u_0 - r(\theta - q_j)^2 - P_j$, where r > 0 is the consumer's disutility rate of consuming an alternative to his preferred product, P_j is the retail price of product j, and u_0 is the base utility of consuming other attributes of the product. This utility function shows that a consumer's utility is

[1] For example, grocery retailers usually carry both skim or low-fat milk and whole or high-fat milk where whole or high-fat milk has a higher cost than skim or low-fat milk due to the expensive input, butterfat.

reduced by the amount $r(\theta - q_j)^2$ when he consumes a type of product other than his ideal type. We use a convex function to represent a consumer's disutility of consuming an alternative type to reflect the likelihood that a consumer's disutility would be increasing at an increasing rate with the difference between the alternative type and his ideal type of product. A consumer is assumed to either purchase one unit of one product or make no purchase. The reservation utility when a consumer does not purchase is $\underline{u} = 0$. To make sure the market exists, i.e., some consumers are willing to buy either the high-cost product or the low-cost product at the lowest possible prices—their respective unit variable costs, the condition, $u_0 > C_H = C_0 + c$, is assumed to hold.

If the cost difference, c, between two types of products is too large relative to consumers' disutility rate, r, of consuming an alternative type of product, a retailer will offer just one type of product, the low-cost product, to consumers because it is too costly to offer the high-cost product. The market with only one type of product does not have horizontal differentiation, and is not interesting in the context of this study. To make sure that both types of products are offered and purchased in equilibrium, a condition which guarantees that the cost difference is not too large compared to consumers' disutility rate needs to hold. Based upon the results of the model, this condition is $2r > c$. Thus, we assume $2r > c$ and focus on the case when both types of products are offered.

In the basic model, the attributes of products are assumed to be predetermined so that the retailer cannot change them, and she can choose only prices to maximize her profit. This assumption is quite consistent with many food products, whose attributes are decided by food producers and processors. Xia relaxes this assumption to study both product attribute choices and price setting decisions of a monopoly seller.

The retailer chooses the optimal prices for two types of products to maximize her profit. In this paper, we examine three competition scenarios: perfect competition, monopoly, and oligopoly. Later we will test which scenarios receive the most empirical support from the data on retail milk prices for California cities.

Perfect Competition

When the retail market for these two products is perfectly competitive, any attempt by a retailer to raise retail prices above unit variable procurement and selling costs will cause all of her customers to switch to other retailers. Thus, a retailer's equilibrium prices for the two types of products are equal to their respective unit variable procurement and selling costs. That is, $P_L = C_L = C_0$ and $P_H = C_H = C_0 + c$. The competitive model of retailer pricing thus predicts that the retail price of each type of product depends on only its own procurement and sales cost and the cost difference between two types of products, c, does not affect the retail price of the low-cost product. Cost changes are reflected fully in changes in the sales price. Consumers' utility of consuming other attributes of a product (u_0) and disutility rate (r) of consuming an alternative type of product also have no effect on the retail prices of both types of products.

The taste value ($\overline{\theta}$) of consumers who are indifferent between buying the low-cost product and buying the high-cost product is

(1) $\overline{\theta} = 1/2 + c/(2r)$.

This taste value, $\overline{\theta}$, is also the percentage of consumers buying the low-cost product (i.e., its market share) and $1-\overline{\theta}$ is the percentage of consumers buying the high-cost product. The equilibrium taste value is increasing in the cost difference and decreasing in consumers' disutility rate of consuming an alternative type of product. An increase in the cost difference means an increase in the price difference in the perfect competition scenario. A larger price difference causes more consumers to purchase the low-cost product. A higher disutility rate means consumers are more reluctant to switch from their preferred type of product to the other type. Thus, consumers are more evenly split between two types of products, which is reflected in a value of $\overline{\theta}$ closer to 1/2. Therefore, the smaller cost difference and/or higher disutility rate lead to fewer consumers purchasing the low-cost product, more consumers purchasing the high-cost product, and the market being more evenly split between the two types of products.

Monopoly

It is reasonable to consider models where retailers may have market power over consumers due to high concentration in local markets, the spatial dimension of grocery retailing, and efforts among grocery retailers to create "product differentiation" relative to their rivals. Most consumers choose one store to do their regular shopping, depending on various store characteristics and overall price levels of stores. Thus, it may be reasonable to model a retailer as a monopolist in setting the prices for any particular good, if price changes for this good have little or no effect on the number of customers coming to this store.

There are two cases for this type of monopoly market: the case where some consumers do not buy either of the two products at the equilibrium and the case where all consumers buy one type of product or the other. To find out the condition that determines which case will prevail, we consider the hypothetical situations where a retailer carries only one type of product, either the low-cost product or the high-cost one. If a retailer offers only the low-cost product, she will set its retail price at $P_L = (2u_0 + C_0)/3$ to maximize her profit and consumers with $\theta \in \left[0, \sqrt{(u_0 - C_0)/(3r)}\right)$ will buy the low-cost product. If a retailer offers only the high-cost product, she will set its retail price at $P_H = (2u_0 + C_0 + c)/3$ to maximize her profit and consumers with $\theta \in \left(1-\sqrt{(u_0-C_0-c)/(3r)},\ 1\right]$ will buy the high-cost product. If the two ranges of consumer tastes do not overlap, that is,

(2) $\sqrt{(u_0-C_0)/(3r)} < 1-\sqrt{(u_0-C_0-c)/(3r)} \Rightarrow 4u_0 < 4C_0+2c+c^2/(3r)+3r,$

the retailer's profit-maximizing price decisions for the two types of products are not interdependent even if she carries both types of products. Thus, if (2) holds, a retailer sets the prices for the two types of products at the same levels as those prices when she carries only one type of product, and consumers with tastes belonging to $\left[\sqrt{(u_0-C_0)/(3r)},\ 1-\sqrt{(u_0-C_0-c)/(3r)}\right]$ do not buy any of the two products. On the other hand, if the two ranges of consumer tastes do overlap, that is,

(3) $\sqrt{(u_0-C_0)/(3r)} \geq 1-\sqrt{(u_0-C_0-c)/(3r)} \Rightarrow 4u_0 \geq 4C_0+2c+c^2/(3r)+3r,$

then the retailer's profit-maximizing price decisions of two types of products will be interdependent when she carries both types of products. Thus, if (3) holds, all consumers will buy one type of product at the equilibrium.

We now focus on the case where all consumers buy one type of product or the other, that is, the market is covered. The taste for the differentiated attribute of consumers who are indifferent between buying the low-cost product and buying the high-cost product is

(4) $\overline{\theta} = 1/2+(P_H-P_L)/(2r)$.

Consumers whose tastes are in the range, $[0,\ \overline{\theta}]$, buy the low-cost product and other consumers whose tastes are in the range, $(\overline{\theta},\ 1]$, buy the high-cost product. (We assume that indifferent consumers buy the low-cost product.) The retailer's profit is

(5) $\pi(P_L,P_H) = (P_L-C_0)\overline{\theta}+(P_H-C_0-c)(1-\overline{\theta})$.

At the equilibrium, consumers with the taste, $\overline{\theta}$, who are indifferent between buying the low-cost and the high-cost product, are also indifferent between buying either type of product and not buying at all. To prove this argument, suppose at the equilibrium that the utility of consumers with preferences $\overline{\theta}$ from purchasing one unit of either type of product, $U(\overline{\theta}, q_L, P_L) = U(\overline{\theta}, q_H, P_H)$, is higher than the reservation utility, $\underline{u} = 0$. Then the retailer can increase her profit by raising both prices by the same amount, ΔP, which is equivalent to the utility difference, $\Delta U = U(\overline{\theta}, q_L, P_L) - \underline{u}$. Raising both prices by ΔP does not affect the value of $\overline{\theta}$ based on equation (4). Then no consumer will change his purchase decision. But all consumers will pay higher prices. Thus the retailer's profit is increased. Therefore, at the equilibrium, consumers who are indifferent between the low-cost and the high-cost product are also indifferent between buying and not buying. That is, $U(\overline{\theta}, q_L, P_L) = U(\overline{\theta}, q_H, P_H) = \underline{u}$. Based on this result, we obtain

(6) $\overline{\theta} = \sqrt{(u_0 - P_L)/r}$ and

(7) $P_H = P_L + 2\sqrt{(u_0 - P_L)r} - r$.

Substituting (4), (6), and (7) into (5), we obtain the retailer's profit as

$$(5') \quad \pi(P_L) = (P_L - C_0)\sqrt{(u_0 - P_L)/r} + \left(P_L + 2\sqrt{(u_0 - P_L)r} - r - C_0 - c\right)\left(1 - \sqrt{(u_0 - P_L)/r}\right).$$

By solving the first-order condition of equation (5') and substituting the solution for P_L back into (6) and (7), we find the equilibrium retail prices of both types of products,

(8) $P_L = u_0 - r\left(\overline{\theta} - 0\right)^2 = u_0 - (3r + c)^2/(36r)$, and

(9) $P_H = u_0 - r\left(1 - \overline{\theta}\right)^2 = u_0 - (3r + c)^2/(36r) + c/3$,

and the equilibrium value of the taste of indifferent consumers,

(10) $\overline{\theta} = 1/2 + c/(6r)$.

The taste value, $\overline{\theta}$, in (10) indicates the market share of the low-cost product, and $1-\overline{\theta}$ is the market share of the high-cost product in the monopoly scenario. The taste value in (10) is less than the taste value in (1) for perfect competition. Thus, compared to perfect competition, fewer consumers purchase the low-cost product and more consumers purchase the high-cost product in the monopoly scenario. The reason is that a monopoly retailer usually sets the price difference between two types of products less than the price difference under perfect competition. The price difference in the monopoly scenario is c/3 but the price difference under perfect competition is c. The smaller price difference results in more consumers buying the high-cost product in the monopoly scenario. As in the perfect competition scenario, the taste value of indifferent consumers is increasing in the cost difference and decreasing in the disutility rate. So a smaller cost difference and/or higher disutility rate will result in fewer consumers buying the low-cost product, more consumers buying the high-cost product, and the market being split more evenly between two types of products. The reason is that a large cost difference causes the retailer to attract more consumers to purchase the low-cost product and fewer consumers to buy the high-cost product and high disutility rate causes the retailer to split consumers more evenly between two types of products.

The equilibrium prices, (8) and (9), show two unique results: the cost difference between the two types of products has a negative effect on the low-cost product price and the common cost component, C_0, surprisingly, has no effect on either product price. The intuition of the cost difference's negative effect on the low-cost product price is straightforward and interesting. When the cost difference between two types of products increases, it becomes relatively more costly for the retailer to sell the high-cost product. Then the retailer wants to encourage more consumers to buy the low-cost product instead of the high-cost product. To achieve this goal, she will lower the price ratio between the low-cost and the high-cost product, P_L/P_H. Any reduced price ratio that includes an increased or unchanged price for the low-cost product implies that the high-cost product price must be increased. But increasing both prices or keeping the low-cost product price unchanged and increasing the high-cost product price will result in some consumers, those whose purchases gave them utility only equal to or a little higher than their reservation utility before the price changes, not buying any product with the new prices. So, as long as the retailer wants to keep the whole market covered, i.e., the condition (3) holds, any reduction in the price ratio must involve reducing the low-cost product price.

Because C_0 is the common cost component of both products, the change of C_0 does not change the cost difference between two types of products for the retailer. Thus, if C_0 changes, the retailer will not induce any consumer to switch from one type to another type of product by changing the relative prices of these two types. This point can also be seen in (10), which shows that the equilibrium value ($\overline{\theta}$) of the taste of indifferent consumers is not affected by C_0. On the other hand, the retailer always sets the two product prices such that indifferent consumers' utility derived from purchasing one type of product is only equal to the level of their reservation utility. Thus, the prices will be determined by the taste value of indifferent consumers and two utility factors, consumers' disutility rate (r) and consumers' utility (u_0) of consuming other attributes, which can be seen from (8) and (9). Therefore, the common cost component, C_0, cannot affect the prices because it has no effect on any of these three factors, the taste value and two utility factors.

The equilibrium prices and the taste value of indifferent consumers also show other important results. First, the high-cost product price is increasing in the cost difference but only partially, in contrast to the competitive case, where the cost difference is fully transmitted to the high-cost product price, i.e., $\partial P_H/\partial c = (3r - c)/(18r) \in (0, 1)$ due to the assumption that $2r > c$. Second, as indicated above, the prices in this monopoly market depend on the taste value of indifferent consumers, consumers' disutility rate, and consumers' utility of consuming other attributes. Thus, both prices are increasing in consumers' utility of consuming other attributes because a high base utility for consumers enables the monopoly retailer to extract more consumer surplus by charging higher prices. Third, both product prices are decreasing in consumers' disutility rate, r. Recall that the retailer wants to cover the whole market when (3) holds. So, the retailer will lower the prices to attract consumers with middle-range tastes to make purchases when a higher disutility rate makes it less attractive for those consumers to buy either type of product.

Oligopoly

If the level of retail prices of the two products has a significant effect on the number of customers choosing to shop at a store, then a retailer cannot act as a monopoly in setting prices for the products because she knows that some customers will switch to other stores if she sets the prices too high. Nonetheless, a retailer may still enjoy some market power due to the aforementioned factors—horizontal concentration, spatial dimension, and store differentiation. In other words, the retail market for the two products may have the characteristics of an oligopoly.

We consider a simple duopoly market where two retailers, A and B, offer both the low-cost and the high-cost product to N consumers who do regular shopping in either one of these two stores. The procurement and selling costs and consumers' taste distribution and utility function are the same as those in previous scenarios. The number of customers coming to a store is negatively affected by this store's price levels of the two products and positively affected by its rival's price levels of the products. We use a simple functional form to represent the number of customers coming to a store as follows:

(11) $M_A = \left[1/2 - \left(P_{A,L} - P_{B,L}\right)/2 - \left(P_{A,H} - P_{B,H}\right)/2\right] N$, and

(12) $M_B = \left[1/2 + \left(P_{A,L} - P_{B,L}\right)/2 + \left(P_{A,H} - P_{B,H}\right)/2\right] N$,

where subscripts A and B are used to represent retailer A and retailer B, respectively. In this functional form, the simple weighted average of two price differences between two stores, the price difference of the low-cost product and the price difference of the high-cost product, affects the number of customers coming to each store.

For the customers who choose to shop at a particular store, we assume their preferences for the differentiated attribute are still uniformly distributed over the range [0, 1]. This means that the effects of the two prices on customers' choices of store are the same across all customers regardless of their preferences for the attribute. In one store, the preferences of consumers who are indifferent between buying the low-cost product and buying the high-cost one is

(13) $\overline{\theta}_i = 1/2 + \left(P_{i,H} - P_{i,L}\right)/(2r)$,

where i = A, B. Consumers whose tastes are in the range, $[0, \overline{\theta}_i]$, buy the low-cost product and other consumers whose tastes are in the range, $(\overline{\theta}_i, 1]$, buy the high-cost product. By using (11), (12), and (13), we obtain the profit functions of retailer A and B,

$$\begin{aligned}\pi_A(P_{A,L}, P_{A,H}) &= \left[\left(P_{A,L} - C_0\right)\overline{\theta}_A + \left(P_{A,H} - C_0 - c\right)\left(1 - \overline{\theta}_A\right)\right] M_A \\ &= \left\{\left(P_{A,L} - C_0\right)\left[1/2 + \left(P_{A,H} - P_{A,L}\right)/(2r)\right] + \left(P_{A,H} - C_0 - c\right)\left[1/2 - \left(P_{A,H} - P_{A,L}\right)/(2r)\right]\right\} \\ &\quad \left[1/2 - \left(P_{A,L} - P_{B,L}\right)/2 - \left(P_{A,H} - P_{B,H}\right)/2\right] N\end{aligned}$$

and

$$\pi_B(P_{B,L},P_{B,H}) = \left[\left(P_{B,L}-C_0\right)\overline{\theta}_B + \left(P_{B,H}-C_0-c\right)\left(1-\overline{\theta}_2\right)\right]M_B$$
$$= \left\{\left(P_{B,L}-C_0\right)\left[1/2+\left(P_{B,H}-P_{B,L}\right)/(2r)\right]+\left(P_{B,H}-C_0-c\right)\left[1/2-\left(P_{B,H}-P_{B,L}\right)/(2r)\right]\right\}$$
$$\left[1/2+\left(P_{A,L}-P_{B,L}\right)/2+\left(P_{A,H}-P_{B,H}\right)/2\right]N.$$

Retailer i chooses her prices, $P_{i,L}$ and $P_{i,H}$, to maximize her profit, $\pi_i(P_{i,L},P_{i,H})$ given the prices charged by her rival. By deriving and solving four first-order conditions simultaneously, we find the equilibrium prices,

(14) $P_{i,L} = C_0 + (c+1)/2 - c^2/(4r)$ and

(15) $P_{i,H} = C_0 + c + 1/2 - c^2/(4r)$,

and the equilibrium value of the taste of indifferent consumers,

(16) $\overline{\theta}_i = 1/2 + c/(4r)$.

The market share of the low-cost product in this oligopoly scenario indicated by the taste value in (16), is less than under perfect competition and larger than in monopoly. Oligopoly retailers have more market power than competitive retailers but less market power than monopoly retailers, so they set the price difference smaller than that of perfect competition and larger than that in the monopoly scenario. The market share of the low-cost product is increasing in the price difference. So the middle-range price difference of the oligopoly scenario results in middle-range market shares for the two types of products. The effects of the cost difference and consumers' disutility rate on the taste value of indifferent consumers and market shares of two types of products in the oligopoly scenario are the same as those in perfect competition and the monopoly scenario. A smaller cost difference and/or higher disutility rate results in fewer low-cost product buyers, more high-cost product buyers, and a more evenly split market.

The impact of the cost difference on the low-cost product price depends on two effects. One effect is that oligopoly competition between stores encourages prices of differentiated products to change in the same direction. Due to oligopoly competition between two stores, the increase of the high-cost product price in one store will push both prices in another store to increase as well. So, when the high-cost product prices in both stores rise due to the increase in the cost difference, the low-cost product prices in both stores will also rise. The other effect comes from a retailer's coordination between her prices of two types of products. As discussed in the monopoly scenario, the cost difference makes the high-cost product costly for a retailer to sell, so she has an incentive to reduce the low-cost product price to attract more consumers to purchase the low-cost product. The total impact of the cost difference on the low-cost product price depends on the relative sizes of these two effects. From (14) and the assumption $2r > c$, we obtain

$$\partial P_{i,L}/\partial c = 1/2 - c/(2r) \begin{array}{ll} > 0 & \text{if } r > c \\ = 0 & \text{if } r = c \\ < 0 & \text{if } c/2 < r < c. \end{array}$$

When $r > c$, consumers' disutility rate of consuming an alternative type of product is large relative to the cost difference, and the price of the low-cost product is increasing with the cost difference between two types of products. This effect in the oligopoly scenario is just the opposite of the effect of the cost difference in the monopoly scenario when the market is covered. Only when $c/2 < r \leq c$, does the cost difference have a non-positive effect on the low-cost product price.

Unlike in a monopoly scenario when the market is covered, retailers cannot push down the indifferent consumers' utility of purchasing one type of product to their reservation utility in an oligopoly competition. Thus, consumers' base utility of consuming other attributes does not affect the equilibrium product prices, but the common cost component does affect prices. Again, these two results in the oligopoly scenario are the opposite of those in the monopoly scenario when the market is covered. The change in the common cost component is fully reflected in the prices of both types of products in the oligopoly scenario.

The derivative of the high-cost product price in (15) with respect to the cost difference, $\partial P_{i,H}/\partial c = 1 - c/(2r)$, belongs to (0, 1) because $2r > c$. Thus, the high-cost product price is increasing with the cost difference, but the change in the cost difference is only partially transmitted to the high-cost product price, which is the same as the effect in a monopoly scenario when the market is covered. But the portion, $1 - c/(2r)$, transmitted is higher in an oligopoly scenario than the portion, $(3r - c)/(18r)$, transmitted in the monopoly scenario when the market is covered. In the oligopoly scenario, larger values of consumers' disutility rate reduce the intensity of competition between two differentiated types of products because consumers are more reluctant to switch to the other type of product. Less competition between the two types of products gives retailers more power to charge higher prices. Thus, both prices are increasing with consumers' disutility rate of consuming an alternative type of product. This is also the opposite of the result in the monopoly scenario when the market is covered.

In the oligopoly scenario, the cost difference has a positive effect and consumers' disutility rate has a negative effect on the taste value of indifferent consumers. Again, a smaller cost difference and/or higher disutility rate will result in fewer consumers buying the low-cost product, more consumers buying the high-cost product, and a more evenly split market. These results and the reasons behind them are the same as, or very similar to, those in the monopoly and perfect competition scenario.

To summarize, the cost difference may reduce the low-cost product price of a monopoly retailer when the market is covered, it can either increase, or decrease, or have no effects on the low-cost product price in the oligopoly scenario, and it has no effect on the low-cost product price under perfect competition. The cost difference is fully transmitted to the high-cost product price in a perfect competition scenario. The transmission is only partial in both the monopoly and the oligopoly scenario although the rate of transmission is higher in the oligopoly scenario. The common cost component of both types of products is fully transmitted to both the low-cost product price and the high-cost product price under both perfect competition and oligopoly competition. The common cost component has no effect on both prices in the monopoly scenario when the market is covered. Consumers' utility from consuming other attributes of a product has a positive effect on both prices in a monopoly scenario when the market is covered but it has no effect on the prices under perfect competition and oligopoly competition. Consumers' disutility rate of consuming a type of product other than their ideal type reduces both prices in the monopoly scenario when the market is covered but it increases both prices in the oligopoly scenario. It has no effect on the prices under perfect competition.

The Empirical Study

The basic conceptual model provides many testable results about the effects of various cost and preference factors on the prices and market shares of horizontally differentiated products under the three competition scenarios. The estimated signs and magnitudes of these effects can also be used to distinguish the forms of competition of a market. Based on these results, we conducted an empirical study on retail milk markets in four California cities. Milk is horizontally differentiated by fat content. Skim milk has zero butterfat, while whole milk has about 3.5%

butterfat.[2] The cost of whole milk is higher because it has more butterfat than skim milk and butterfat is expensive. Replacing the low-cost product and the high-cost product in the basic model by skim milk and whole milk, respectively, we can apply the results of the basic conceptual model to the case of the retail milk market. Therefore, according to the basic model, the cost difference, the common cost component, consumers' utility of other attributes (non-fat contents of milk), and consumers' disutility rate will have different effects on the prices of skim milk and whole milk under the three different competition scenarios. However, we have no way to estimate and test the effects of the two preference factors, consumer's utility of consuming non-fat contents and consumers' disutility rate of purchasing a type of milk other than their ideal type, because the data on those utility factors are not available. Therefore, we focus the empirical study on the effects on retail milk prices of the two cost factors, the cost difference and the common cost component (for which good data are available) and reveal competition characteristics of retail milk markets based on those estimated effects.

We use time-series data of retail skim milk and whole milk prices, the skim-whole cost difference, and the common cost component for skim and whole milk to estimate price equations of both skim milk and whole milk for four California cities. We examine the effects of the two cost factors on retailer prices and conduct hypothesis tests based on the conceptual results to characterize the competition for retail milk markets in these cities.

The supply of fluid milk involves farmers, processors, and retailers. Farmers provide raw milk to processors. Then processors process raw milk and sell the finished fluid milk to retailers. Retailers sell fluid milk to consumers. Depending on the form of competition in retail markets, retail prices of skim milk and whole milk may be affected by four cost and preference factors,

[2] In reality, grocery retailers usually also carry other types of milk, e.g. milk with 1% or 2% butterfat. We assume they carry only two types of milk in the model to simplify the analysis.

the cost difference between whole and skim milk, the common cost component, consumers' utility of non-fat contents, and the disutility rate. In addition, milk retail prices are also affected by other demand-shift and cost-shift variables, such as prices of substitute beverages, retailers' costs for labor, energy for cooling, etc. As in the basic model, we use the variable, c, to represent the cost difference between two types of milk and the variable, C_0, to represent the common cost component, which is equal to retailers' cost of skim milk. Any changes over time in consumers' utility for non-fat contents, the disutility rate, and other demand shifters and cost shifters are captured by a time trend variable, TIME. The effects of unmodeled demand and cost factors are captured by the constant term. Thus, the econometric models of retail prices of skim milk and whole milk are specified as follows:

$P_s = \alpha_s + \beta_{s,1}c + \beta_{s,2}C_0 + \beta_{s,3}TIME + \varepsilon_s$ and

$P_w = \alpha_w + \beta_{w,1}c + \beta_{w,2}C_0 + \beta_{w,3}TIME + \varepsilon_w$,

where P_s and P_w are skim milk retail price and whole milk retail price, respectively, and ε_s and ε_w are error terms.

For the econometric model of retail milk prices of a city, the errors may be contemporaneously correlated across the two price equations because the effects of some factors excluded from the econometric model may be captured in the errors of both price equations. We thus use the seemingly unrelated regression (SUR) method to jointly estimate two milk price equations for a city. The SUR estimation also allows us to conduct hypothesis tests on across-equation restrictions to characterize market competition.

Estimation Results

We conducted empirical studies on retail milk markets in four California cities, Sacramento, San Francisco, Los Angeles, and San Diego, for the period from April 1999 through November 2003.

California has its own stabilization and marketing plans for market milk for both northern California and southern California marketing areas. These plans assure dairy farmers reasonable minimum prices by setting minimum monthly milk prices and milk components prices for various classes of milk. Fluid milk belongs to Class I. We obtained these minimum farm prices of Class I milk components from various issues of the *California Dairy Information Bulletin*. Using these milk component prices and federal component standards of milk for California, we calculated the minimum farm prices of skim milk and whole milk for both the northern California and southern California marketing areas. A limitation of using these calculated farm prices is that they do not take possible over-order premiums into account. An over-order premium is a fee for milk sold above the regulated minimum price and is usually related to services provided by milk marketing cooperatives. Data of over-order premiums are not publicly available.

Retailers' costs of skim milk and whole milk include wholesale prices paid to processors and selling cost. When the wholesale milk market is perfectly competitive, wholesale prices are the sum of farm prices and processing costs. By assuming the wholesale milk market is competitive, retailers' cost of skim milk is equal to the sum of farm price of skim milk, processing cost, and selling cost. By definition, the common cost component is equal to retailers' cost of skim milk. So the common cost component is equal to the skim milk farm price plus processing and selling costs. Due to lack of data on processors' processing cost and retailers' selling cost, we used the farm price of skim milk to represent the common cost component, C_0, and then the effects of processing costs and selling costs are implicitly captured by both the constant term and the time trend.

During processing, raw milk is first separated by component and then various components are re-assembled according to different content formulas to make the final products, such as different types of fluid milk including skim milk and whole milk. So it is reasonable to think that processing cost of skim milk is the same as that of whole milk. Also retailers' selling costs for skim milk and whole milk are likely the same. Thus, retailers' cost difference, c, between skim milk and whole milk is equal to the difference between the skim milk farm price and whole milk farm price. We calculate the farm price difference between skim milk and whole milk and use it to represent the cost difference, c.

The ideal data set for milk retail prices for this analysis are store-level data, which to date we have been unable to obtain. Instead, we use average monthly retail prices of skim milk and whole milk for the four California cities, as reported in various issues of the *California Dairy Information Bulletin*. The summary statistics of the data of the cost difference, the common cost component, and retail prices of skim milk and whole milk for four California cities are reported in table 1. There are significant variations in both costs and prices during the time period under study. Sacramento and San Francisco have the same cost data because they both are subject to regulations of the northern California marketing area. Los Angeles and San Diego, which belong to southern California marketing area, also have same costs data due to facing the same regulations. On the other hand, retail price levels and their fluctuations are quite different across cities.

The estimation results and hypothesis tests for four California cities, Sacramento, San Francisco, Los Angeles, and San Diego, are reported in tables 2 and 3. The model fits the data very well for each city. Most parameter estimates are statistically significant and the adjusted R^2

statistics are high, ranging from 0.83 in the equations for San Diego to 0.98 in the equations for Sacramento.

The estimation results also show that the error terms exhibit a first-order autocorrelation process, $\varepsilon_t = \rho_1 \varepsilon_{t-1} + u_t$, for all four cities except the whole milk price equation for San Francisco, which has both first-order and second order autocorrelation processes. The estimates of ρ_1 in all equations with only a first-order autocorrelation process are statistically positive and less than 1 so that the autocorrelation process is stable. This result means that shocks in exogenous variables including the cost difference and the common cost component are gradually transmitted to retail milk prices in a certain time period whose length is indicated by the value of ρ_1. A large ρ_1 implies the transmission period is long. The values of ρ_1 in table 3 show that Los Angeles and San Diego have longer transmission processes than Sacramento and San Francisco.

We conducted hypothesis tests on the effects of two cost factors on retail milk prices to characterize market competition for each city. Based on the conceptual results for the basic model, we obtained the null hypotheses for each of three competition scenarios: perfect competition, monopoly, and oligopoly competition. For perfect competition, we jointly tested four null hypotheses, $\beta_{s,1} = 0$, $\beta_{w,1} = 1$, $\beta_{s,2} = 1$, and $\beta_{w,2} = 1$, which mean the cost difference has no effect on the skim milk price but is fully transmitted to the whole milk prices and the common cost component is fully transmitted to both milk prices. For the monopoly scenario, we jointly tested two null hypotheses, $\beta_{s,2} = 0$ and $\beta_{w,2} = 0$, which mean the common cost component has no effect on both milk prices. We also separately tested two other null hypotheses, $\beta_{s,1} < 0$ and $\beta_{w,1} > 0$, which mean the cost difference has a negative effect on the skim milk price and a positive effect on the whole milk price. For the oligopoly scenario, we jointly tested two null hypotheses, $\beta_{s,2} = 1$ and $\beta_{w,2} = 1$, which mean the common cost component is fully transmitted to both milk prices. We also separately tested another null hypothesis, $\beta_{w,1} > 0$, which means the cost difference has a positive effect on the whole milk price.[3] The impact of the cost difference on the skim milk price can be positive, zero, or negative in the oligopoly scenario, so there is no need to conduct a hypothesis test for this effect. The results and conclusions of the joint hypothesis tests are reported in table 3. The results of the separate hypothesis tests can be inferred from the coefficient estimates and their significance levels in table 2.

For three cities, Sacramento, San Francisco, and Los Angeles, the test results reject the four jointly tested null hypotheses of the perfect competition scenario and two jointly tested null hypotheses of the monopoly scenario. The results also reject one separately tested hypothesis, $\beta_{s,1} < 0$, of the monopoly scenario. The results do not reject another separately tested hypothesis, $\beta_{w,1} > 0$, of the monopoly scenario. But this effect of the cost difference, $\beta_{w,1} > 0$, can also be observed in the oligopoly scenario. The test results do not reject both two jointly tested null hypotheses and one separately tested null hypothesis of the oligopoly scenario. Therefore, the hypothesis test results strongly support that the retail milk markets are under oligopoly competition in these three cities.[4] For San Diego, the test results reject the jointly tested hypotheses for both perfect competition and the monopoly scenario and one separately tested hypothesis, $\beta_{s,1} < 0$, of the monopoly scenario. Although the test results also reject the jointly

[3] We did not jointly test all null hypotheses in either the monopoly scenario or the oligopoly scenario because each scenario has one or two hypotheses involving inequality. The inequality hypotheses cannot be tested jointly with other equality hypotheses using several common computer econometric programs, such as E-view, Shazam, etc. Therefore, we jointly tested the equality hypotheses and separately tested the inequality hypotheses.

[4] Cotterill and Brundage examine the transmission of milk prices from farm to retail and conclude that San Francisco's retail milk market seems competitive but they suspect that the market margin between farm prices and retail prices could be wider than what would prevail in a competitive market. The test results of this paper strongly support a retail milk market under oligopoly competition for San Francisco and verify their suspicion. The comparison between their study and this paper shows that the simple examination of the transmission of milk prices from farm to retail may not unveil the imperfect competition of a market.

tested hypotheses for the oligopoly scenario, the separately tested hypothesis, $\beta_{w,1} > 0$, is not rejected. Therefore, the hypothesis tests show that San Diego's retail milk market is closer to oligopoly competition than to the monopoly scenario and perfect competition.

The results of empirical studies on milk retail markets in five cities in the neighboring areas of California, Phoenix, Denver, Salt Lake City, Seattle, and Portland, for the period from January 2000 through November 2003, are reported in Xia.

Conclusions

Markets for horizontally differentiated products with differential costs are important and have unique features. This paper studies sellers' pricing strategy and market equilibrium in these markets under various competition scenarios in the context of retail milk markets. The cost and utility factors have quite different effects on prices of differentiated products under various competition scenarios, as the conceptual analysis demonstrated.

We used the predictions from the conceptual model to conduct an empirical study of the effects of cost factors on retail milk prices and to characterize competition in retail milk markets in four California cities. The econometric model explains retail prices of both skim milk and whole milk very well for all California cities. The hypothesis test results strongly support the oligopoly-pricing hypothesis for three California cities. The oligopoly scenario also receives more empirical support than the other two competition scenarios for the fourth city, San Diego.

Table 1. Summary Statistics of Costs and Prices ($ per gallon).

Cities	Cost difference (c)		Common cost (C_0)		Skim milk retail price (P_s)		Whole milk retail price (P_w)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Sacramento	0.38	0.11	0.84	0.11	2.28	0.14	2.72	0.24
San Francisco	0.38	0.11	0.84	0.11	2.36	0.15	2.69	0.24
Los Angeles	0.38	0.11	0.84	0.11	2.76	0.18	2.84	0.21
San Diego	0.38	0.11	0.84	0.11	2.78	0.14	2.77	0.21

Table 2. Estimation Results of California Cities.

Parameters (variables)	Sacramento		San Francisco		Los Angeles		San Diego	
	Skim	Whole	Skim	Whole	Skim	Whole	Skim	Whole
α_s, α_w (constant)	1.13* (18.7)	1.12* (10.2)	1.28* (18.2)	1.02* (7.47)	2.15* (13.9)	1.93* (12.6)	2.00* (12.8)	1.91* (12.2)
$\beta_{s,1}$, $\beta_{w,1}$ (c)	0.29* (4.20)	0.88* (7.19)	0.20* (2.40)	0.79* (4.86)	0.08 (0.47)	0.65* (5.43)	0.32* (2.14)	0.80* (4.60)
$\beta_{s,2}$, $\beta_{w,2}$ (C_0)	1.08* (16.0)	1.08* (10.4)	1.12* (15.0)	1.29* (8.73)	0.88* (5.81)	0.84* (8.03)	0.71* (5.88)	0.70* (4.87)
$\beta_{s,3}$, $\beta_{w,3}$ (TIME)	0.005* (8.58)	0.012* (6.19)	0.003* (3.50)	0.01* (6.92)	-0.01* (2.43)	-0.00 (0.08)	0.002 (0.60)	-0.00 (0.20)
ρ_1	0.54* (4.48)	0.70* (5.76)	0.28* (2.31)	0.52* (4.33)	0.84* (7.02)	0.99* (9.05)	0.82* (6.56)	0.63* (4.96)
ρ_2	-0.06 (0.60)	0.07 (0.57)	0.24* (2.70)	-0.004 (0.03)	-0.16 (1.37)	-0.13 (1.20)	-0.007 (0.06)	0.11 (0.89)
$\bar{R}^2$	0.98		0.93		0.88		0.83	
D.W.	1.96		1.65		1.91		1.81	

Notes: The t-statistics are in parentheses. Statistical significance at the 10% level is represented by *. ρ_1 and ρ_2 are the coefficients in the autocorrelation form of the error terms, $\varepsilon_t = \rho_1\varepsilon_{t-1} + \rho_2\varepsilon_{t-2} + u_t$.

Table 3. Hypothesis Tests of Competition Scenarios for California Cities.

	Scenarios	Null hypotheses (H_0)	Test results	Conclusions*
Sacramento	Perfect Competition	$\beta_{s,1}=0$, $\beta_{w,1}=1$ $\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 9.71 Prob. 0.00	Reject H_0
	Monopoly	$\beta_{s,2}=0$, $\beta_{w,2}=0$	F-stat. 132 Prob. 0.00	Reject H_0
	Oligopoly	$\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 0.68 Prob. 0.51	Do not reject H_0
San Francisco	Perfect Competition	$\beta_{s,1}=0$, $\beta_{w,1}=1$ $\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 5.68 Prob. 0.00	Reject H_0
	Monopoly	$\beta_{s,2}=0$, $\beta_{w,2}=0$	F-stat. 113 Prob. 0.00	Reject H_0
	Oligopoly	$\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 2.11 Prob. 0.13	Do not reject H_0
Los Angeles	Perfect Competition	$\beta_{s,1}=0$, $\beta_{w,1}=1$ $\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 3.78 Prob. 0.01	Reject H_0
	Monopoly	$\beta_{s,2}=0$, $\beta_{w,2}=0$	F-stat. 41.2 Prob. 0.00	Reject H_0
	Oligopoly	$\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 1.28 Prob. 0.28	Do not reject H_0
San Diego	Perfect Competition	$\beta_{s,1}=0$, $\beta_{w,1}=1$ $\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 4.24 Prob. 0.00	Reject H_0
	Monopoly	$\beta_{s,2}=0$, $\beta_{w,2}=0$	F-stat. 20.9 Prob. 0.00	Reject H_0
	Oligopoly	$\beta_{s,2}=1$, $\beta_{w,2}=1$	F-stat. 3.64 Prob. 0.03	Reject H_0

Note: * Null hypotheses are rejected at the 90% significance level. That is, a null hypothesis is rejected when the probability of the F-statistic is less than 0.10.

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