Division of Research
School of Business Administration
The University of Michigan

May, 1992

DYNAMIC PRICING OF DURABLES IN DUOPOLY: THE EFFECT OF BUYER EXPECTATIONS

Working Paper No. 687

Rabikar Chatterjee*
The University of Michigan
and
Peter Crosbie**
Leavey School of Business

*School of Business Administration, The University of Michigan, Ann Arbor MI 48109-1234.
**Leavey School of Business, Santa Clara University, Santa Clara CA 95053.

ABSTRACT

This paper examines the problem of dynamic pricing of durables in a competitive market in which customers form expectations about future prices of the competing products. More specifically, we assume a duopoly in which firms may sell products differentiated by their level of quality. One firm sells a 'basic' model while the other may sell a higher quality model with a possible cost disadvantage. Customers are heterogeneous with respect to their valuations of the new product, and form rational expectations.

Our results demonstrate the impact of customer expectations on market evolution and the pattern of prices. Future price expectations can be instrumental in forcing the lower quality brand from the market during the early part of the planning horizon. Customers benefit from foresight while the effect on the firms can be mixed. If the higher quality firm can force its competitor to withdraw from the market, its profits can increase relative to the case of myopic customers. The profits of the lower quality firm are always reduced by the presence of future expectations.

1. Introduction

The importance of price in a buyer's adoption decision for a new durable has long been recognized by researchers and practitioners alike. Indeed, many studies have found that, of all the elements of the marketing mix, price explains the most variance in purchasing behavior (Lambin 1976; Elrod and Winer 1982). Further, other studies have demonstrated that the current price as well as customers' expectations of future prices influence the purchase decision (Winer 1985; Doyle and Saunders 1985).

Of particular interest is the impact of customer expectations on the dynamic (intertemporal) pricing decision of a durable goods marketer. While recognizing the importance of future expectations, the marketing science literature on dynamic pricing of durables has, until recently, focused typically on demand (and cost) dynamics, without incorporating the effect of customer expectations (Kalish 1983; Mahajan, Muller, and Bass 1990). Economists, on the other hand, have developed a stream of research on price expectations and durable goods under the assumption that customers form rational expectations, that is, customers use all the available information to form unbiased forecasts. Thus, in a deterministic environment, this assumption implies, in essence, that customers' predictions are correct (Stokey 1979, 1981; Bulow 1982, 1986; Conlisk et al. 1984; Suslow 1986; Gul et al. 1986; Asubel and Deneckere 1987). More recently, the rational expectations assumption has been employed in marketing and management science to model the effect of customer expectations (Moorthy 1988; Narasimhan 1989; Levinthal and Purohit 1989; Besanko and Wilson 1990).

This stream of research uses a game theoretic framework, where the players are the customers on the one hand and a monopoly seller on the other. Thus, this literature does not consider the impact of competition on the evolution of prices (and possibly other variables). Dynamic pricing models without price expectations, however, have been extended to incorporate competition (Clarke and Dolan 1984; Thompson and Teng 1984; Rao and Bass 1985; Eliashberg and Jeuland 1986).

Our objective is to examine dynamic pricing of durables in a competitive market in which customers form expectations about future prices of the competing products. More specifically, we assume a duopoly in which firms may sell products differentiated by their level of quality. One firm sells a 'basic' model while the other may sell a higher quality model (e.g., with added features). The quality levels are exogenously specified; that is, the model examines the pricing decision for either firm, given the quality levels[1]. Customers are heterogeneous with respect to their valuations of the new product, and form rational expectations.

Evidence suggests that customers do form expectations about future product attributes and prices (Winer 1985; Holak et al. 1987). Furthermore, manufacturers are keenly aware of the potential impact of customers' future expectations on current sales. For example, in the computer industry, manufacturers go to great lengths to assure customers that future products will be compatible with current ones and commonly offer generous upgrade policies (Moorthy 1988). Chrysler recently offered to guarantee its cash rebate policy: If the rebate increased within the next twelve months, customers who bought under the old rebate would receive makeup payment. Ford's dealers were concerned that public awareness of the automaker's planned increase in incentives for its 1990 models at the end of the season would hurt their current sales (Patterson 1990).

While customers may not normally possess the perfect foresight implied by the rational expectations assumption, this framework may be viewed as a conceptually useful benchmark. Between the two extremes of perfect foresight and zero foresight (the myopic customer typically assumed in the marketing literature on dynamic pricing models) lies an infinite range of assumptions of "less-than-fully-rational" expectations. Rational expectations in our model implies that customers are fully informed about the firms' costs and the distribution of customer reservation prices: this assumption may serve as a good approximation particularly in business-to-business marketing situations characterized by a small number of sophisticated buying firms.

Our analysis examines the effect of customer expectations on the competitive interaction between the firms. In particular, we look for a possible interactive effect between customer expectations and the interfirm difference in product quality on the relative performance of the firms. The implications of this investigation are particularly interesting, given the current managerial and research focus on product quality as a critical strategic variable.

---

[1] While the quality decision is exogenous to the pricing model that is the focus of this paper, we should point out that, in our framework, the level of quality selected by the second firm (given that the first firm makes the basic model) depends on the relationship between unit cost and quality.

The paper is organized as follows. In the next section, we briefly and selectively review the literature, focusing on motivating our rational expectations framework. Section 3 develops the model and discusses some key implications of future expectations on the competitive interaction between firms. In Section 4, we report the results of simulation analysis examining the impact of the model's parameters on the equilibrium in a five-period horizon. We conclude in Section 5 with a review of our results and their implications, and a discussion of the model's limitations and directions for future research.

2. Literature Review: Rational Expectations and Durable Goods Pricing

The stream of research on price expectations and durable goods was first motivated by the seminal paper by Coase (1972), who conjectured that a monopolist selling a durable product to a market of nonmyopic customers with rational (that is, correct) expectations will be forced to sell at marginal cost (see Stokey 1981 and Bulow 1982 for formal proofs of this conjecture). Coase's argument can be described as follows. In the absence of expectations, customers make a decision to buy or not based only on the current price. A monopolist, wanting to skim the market, will start off by offering a price equal to the highest valuation, then lower the price to the next highest valuation and so on. However, if customers have rational expectations, they can anticipate that the monopolist has an incentive to keep lowering the price and will decide to wait. Unless the monopolist is able to credibly commit to holding the price for any length of time, its skimming strategy quickly collapses. The monopolist, knowing that all the customers are going to wait until it lowers the price, sees no point in offering a sequence of prices at all and decides to launch the product at marginal cost.

Note that two assumptions, the inability of the firm to credibly commit to a price and rational expectations, are critical to the above argument. However, in the *discrete* time framework, the monopolist can design its best schedule (with prices above marginal costs), given its ability to commit to holding price for the duration of each discrete time period. This situation corresponds to a manufacturer who is unable to persuade customers that it will not lower price on a new product in the near future. Thus, the customers who value the product very highly buy it immediately while others, with lower valuations, wait for the price to be lowered. The discrete time framework introduces a cost of waiting that customers incur between price changes. (In the continuous time framework, there is no time between price changes and thus the cost of waiting between successive "periods" is zero.) In the discrete time framework, the monopolist's profits decline as each of the assumptions of customers' rational expectations and the monopolist's inability to commit to a price schedule is successively applied. Each assumption adds constraints to the monopolist's profit maximization problem. (Note that in the absence of price expectations the commitment assumption becomes redundant.)[2]

Economists have enriched the basic models of the Coase conjecture with extensions generally centered around some mechanism which essentially allows the monopolist to commit to holding their price for extended periods of time. These include, for example, allowing the monopolist to lease the product rather than sell it outright, and introducing planned obsolescence (Bulow 1986). A further approach (Conlisk, Gerstner and Sobel 1984), introduces continuous growth in the market potential. The resulting price paths from these models follow either a monotonic decline (a price skimming strategy) or some variant of cyclic pricing.

Drawing from the research streams of rational expectations in economics and diffusion models in marketing, Narasimhan (1989) considers a model where there are two types of customers differing in their reservation prices. Every period new customers enter the market, where the number entering is governed by a Bass (1969) type diffusion model. The customers form rational expectations about future prices, behave strategically and desire at most one unit of the product. The price path of a monopolist selling to this market is shown to follow a cyclical pattern. The length of the price cycles and the depth of discount are functions of the relative reservation prices and population proportions of the customers types, and the relative values of the Bass innovation and imitation coefficients.

Moorthy (1988) relaxes to some extent the assumption of perfect customer foresight. In his two period model, customers have heterogeneous reservation prices and are able to

[2] These results require that customers form expectations based only on the current price, that is, form stationary beliefs. If instead consumers are assumed to form expectations based on the entire history of past prices, the Coase result need not hold. Gul et al. (1986) show that a continuum of equilibria exist of which only the special class weakly obeying the stationary belief assumption conform to the Coase conjecture. Ausubel and Deneckere (1987) show that the firm may be able to sustain a reputation strategy, thus maintaining their ability to commit to holding price. However, in a discrete time framework with a fixed planning horizon and a limited number of periods, there is little difference between the equilibria. We assume that customers form stationary beliefs, in a manner similar to the models of Stokey (1981), Bulow (1982) and Besanko and Winston (1990).

correctly anticipate future prices *if* they know the monopolist's cost. However, they are uncertain about the monopolist's cost and form expectations of the future price based on the first period price. Assuming that the monopolist's cost can only take on one of two values (high or low), Moorthy explores the following question: can a low-cost monopolist masquerade as a high-cost firm in the first period (and thus charge a high price), and then in the second period surprise the customers and take advantage of his low costs by charging a much lower price? Moorthy shows that this is not possible; the monopolist finds it optimal to price such that he reveals his true cost in the first period. This result thus lends some support to the robustness of the results from rational expectations based models.

Besanko and Winston (1990) develop a multi-period model with a market consisting of a monopolist selling a durable to a continuum of customers with reservation prices uniformly distributed over an interval. They characterize the subgame perfect Nash equilibrium pricing policy which is shown always to involve intertemporal price discrimination.[3] Comparing the pricing policies for the monopolist facing myopic and nonmyopic customers, Besanko and Winston find that for any given level of penetration, prices are always lower with nonmyopic customers.[4] Further, for all reasonable values of the model's parameters, there are large differences in the optimal price paths. Besanko and Winston also show that profits are considerably less if a monopolist facing nonmyopic customers implements the optimal myopic pricing policy.

Our model extends Besanko and Winston's framework to include competition in a duopoly setting. To the best of our knowledge, this is the first attempt to model explicitly the effect of competition in this type of rational expectations framework.

---

[3] A subgame perfect Nash equilibrium (Selten 1975) is a Nash equilibrium whose strategies form a Nash equilibrium for each subgame. A subgame is, loosely speaking, a game within a larger game and in this context is the planning horizon in any period through to the final period. For example, in a model with T periods, the T subgames are represented by the planning horizons, 1-T, 2-T, ..., t-T, ..., T. In practice, restricting the equilibrium to be subgame perfect rules out unreasonable commitments by the monopolist (for example, committing to never lower price in future periods when they will always find it profitable to do so).

[4] Nonmyopic customers form rational expectations about future prices while myopic customers do not consider the future at all.

3. The Model

Buyer Behavior: Implications of Price Expectations

We assume that the market consists of two firms, A and B, and a continuum of customers. Each customer purchases at most one unit of the product. A customer's reservation price for the basic model sold by B is denoted by ϕ and the reservation price for the superior (high quality) model sold by A is ϕk, where k is a quality parameter. Customers' reservation prices for the basic model, ϕ, are distributed uniformly on the interval [0,1].[5]

Product launch by firms A and B may be simultaneous or sequential. We first consider the case in which the firms launch simultaneously. The firms must set a price in each of T periods, p_{it} (i = A or B), with $t \in \{1,...,T\}$ denoting a typical period and t = 1 representing the launch period. The implications of the customers' rational expectations for buyer behavior are captured by the following conditions of adoption and choice for brand i in period t (given that the customer has not adopted so far), i = A, B; t = 1, ..., T:

(1) The price of brand i in t period must not exceed the customers' reservation price,

$$\phi\Delta_i - p_{it} \geq 0, \qquad (1.)$$

where $\Delta_A = k$ and $\Delta_B = 1$.

(2) The consumer surplus from adopting brand i (the difference between price and reservation price) must exceed the consumer surplus from adopting brand j in period t,

$$\phi\Delta_i - p_{it} \geq \phi\Delta_j - p_{jt}, \; i \neq j. \qquad (2.)$$

(3) The consumer surplus from adopting brand i must exceed the discounted consumer surplus from adopting either brand in any subsequent period,

$$\phi\Delta_i - p_{it} \geq \delta^{t_1 - t}\left(\phi\Delta_j - p_{jt_1}\right) \;\; \forall t_1, t \leq t_1 \leq T \qquad (3.)$$

Condition (1) is straightforward. Condition (2) reflects utility maximizing choice behavior while condition (3) extends this to inter temporal utility maximization by a customer possessing perfect foresight.

---

[5] This is equivalent to scaling customers' reservation prices by $\frac{1}{\delta^+}$, where δ^+ is the maximum reservation price of population.

The interaction of the nonmyopic customers and the competing firms can potentially result in a number of possible adoption patterns. The exposition is simplified by initially assuming that the firms' marginal costs $c_A, c_B < 1$ are equal, $c_A = c_B$, and that the game is set in two periods, T = 2. We will later relax these restrictions.

Figure 1 shows two potential adoption patterns for the two-period case. The line represents the continuum of customers in descending order in terms of their reservation prices for the basic model (from 1 to 0). The segments are denoted by F_t, (F = A, B; t = 1, 2), representing sets of customers who buy F in period t. For ease of exposition, we designate customers by their reservation prices for the basic model (i.e., customer ϕ refers to the customer with reservation price ϕ). We can rule out patterns other than the two in Figure 1 by noting that if some customer ϕ^B adopts B in a particular period, then no customer ϕ, $\phi \leq \phi^B$, will adopt A in that period because $\phi k \geq \phi$ (condition 2). Similarly, if some customer ϕ^A adopts A in a particular period, then a customer ϕ, $\phi \geq \phi^A$, who has not yet adopted, will also adopt A in that period. Thus, the adoption and choice conditions imply *contiguous* adoption patterns in the order shown in Figure 1.

Case I of Figure 1 is the most obvious pattern. In Period 1 the customers with the highest reservation prices adopt Brand A, while those with lower reservation prices adopt Brand B. This pattern repeats itself in Period 2. The boundary reservation prices for this case are defined by the following:

$$\phi_1 k - p_{A1} = \phi_1 - p_{B1} \qquad \text{from (2),} \qquad (4.)$$

$$\phi_2 - p_{B1} = \delta\left(\phi_2 k - p_{A2}\right) \qquad \text{from (3),} \qquad (5.)$$

$$\phi_3 - p_{B2} = \phi_3 k - p_{A2} \qquad \text{from (2),} \qquad (6.)$$

and $$\phi_4 - p_{B2} = 0 \qquad \text{from (1).} \qquad (7.)$$

We can see the condition necessary for the adoption pattern shown as Case II in Figure 1 by rearranging (5) as

$$\phi_2\left(1 - \delta k\right) = p_{B1} - p_{A2} \qquad (5')$$

and noting that any customer ϕ, $\phi_1 > \phi \geq \phi_2$, will adopt B if and only if $\delta k \leq 1$, resulting in Case I. However, if $\delta k > 1$, these customers will prefer to wait and adopt A in Period 2, yielding the pattern in Case II. Thus A's quality advantage k, and customers' willingness to wait (δ) combine to provide A with a "multi-period" quality advantage, $\delta k > 1$. The boundary reservation prices for this case are easily seen to be defined by:

$$\phi_1 k - p_{A1} = \delta\left(\phi_1 k - p_{A2}\right) \qquad \text{from (3),} \qquad (8.)$$

$$\phi_2 - p_{B1} = \delta\left(\phi_2 k - p_{A2}\right) \qquad \text{from (3),} \qquad (9.)$$

$$\phi_3 - p_{B1} = \delta\left(\phi_3 - p_{B2}\right) \qquad \text{from (3),} \qquad (10.)$$

and

$$\phi_4 - p_{B2} = 0 \qquad \text{from (1).} \qquad (11.)$$

In addition, in Period 2 A will set its price such that customer ϕ_3 is indifferent between A and B. Thus,

$$\phi_2 k - p_{A2} = \phi_2 - p_{B2} \qquad (12.)$$

must also hold. Comparing (9), (10) and (12), it is clear that $\phi_2 = \phi_3$. That is, either $B_1 = \varnothing$ or $B_2 = \varnothing$.[6] If $B_2 = \varnothing$ then B must be able to credibly commit to withdrawing its product from the market in the second period. The only way it could do that would be to show customers that it would have no profit motive to sell in Period 2 by selling at its marginal cost in Period 1. B would always be better off delaying entry into the market and pricing above cost in Period 2 and therefore, in equilibrium, $B_1 = \varnothing$.

If $c_A > c_B$, then it is possible that B may be able to profitably set a price in Period 2 such that $A_2 = \varnothing$. In this case, the adoption pattern would become $A_1B_1B_2$ or possibly A_1B_2. We summarize the possible equilibrium adoption patterns:

	$1 \geq \delta k$	$1 < \delta k$
$c_A = c_B$	$A_1B_1A_2B_2$	$A_1A_2B_2$
$c_A > c_B$	$A_1B_1A_2B_2$ or $A_1B_1B_2$	$A_1A_2B_2$ $A_1B_1B_2$ or A_1B_2

The resulting patterns described above for the two-period case can be generalized to longer planning horizons. Proposition 1 and Corollary 1 establish that customers will adopt in order of decreasing reservation price. That is, customers with higher reservation prices adopt before customers with lower reservation prices.

6 That is, the set of customers who buy B in Period 1 (2), B1 (B2), is the empty set, $\varnothing$.

PROPOSITION 1

In a subgame perfect Nash equilibrium, if $\delta k > 1$, then $t^A \leq t_B \leq T$, where t^A is the *last* period in which A makes any sales, t_B is the *first* period in which B makes any sales, and T is the final period of the finite horizon game.

Proof: See Appendix.

This result restricts the adoption patterns possible and leads to the following result.

COROLLARY 1 TO PROPOSITION 1

In a subgame perfect Nash equilibrium if customer ϕ adopts in period t, then a customer ϕ', $\phi' \geq \phi$ will adopt in some period $\tau, \tau \leq t$.

Proof: See Appendix.

This implies that when $\delta k > 1$ the adoption patterns possible in equilibrium are restricted to the form:

$$A_1 A_2 \ldots A_\tau B_\tau B_{\tau+1} \ldots B_T \ .$$

This means that the only way for B to make any sales (in other than the terminal period) when A has an intertemporal quality advantage, $\delta k > 1$, is to force A from the market. That is, price so low that A is unable to make any profitable sales. For this strategy to be profitable for B, it must have a cost advantage over A, $c_A > c_B$. Conversly, if the firms have equal costs, then we have the following result:

COROLLARY 2 TO PROPOSITION 1

If $\delta k > 1$ and $c_A = c_B$ then the *only* period in which firm B makes any sales is the final period of the game, T.

Proof: See Appendix.

Thus, customers with future expectations are able to alter considerably the structure of the market. In some circumstances, Firm A is able to use its quality advantage and the customer's future expectations to block B from entering the market. Firm A cannot do this selling to a market of myopic customers.

It is of some interest to ask if B can overcome A's quality advantage by beating it to the market. That is, can B act as a pioneer and launch its basic model before A can get its higher quality product to market? Unfortunately for B, the answer is no, if A's quality advantage is "sufficiently" large (as quantified below). To see why, consider the two-period case where only B can launch in Period 1 but both A and B can sell in Period 2, and $\delta k > 1$. This is the same as Case II discussed above except A is not available in Period 1. The boundary constraints (9), (10) and (12) must still hold. Thus, it again follows that in equilibrium $B_1 = \varnothing$. That is, even though B can act as a pioneer it is better off delaying the launch of its product until Period 2. Corollary 3 to Proposition 1 extends this result to cases where B has a multi-period development lead.

COROLLARY 3 TO PROPOSITION 1

In a subgame perfect Nash equilibrium, if $k\delta^{t_A} > 1$, then $t^A \le t_B \le T$, where t_A is the *first* period in which A can enter the market and t^A, t_B and T are as defined in Proposition 1.

Proof: See Appendix.

Thus, if B chose to launch ahead of A, A would retaliate by pricing low once it did enter. Customers would anticipate A's iminent launch at a low price and demand an even lower price to adopt B. Indeed, the only way for B to launch before A is to price at marginal cost and thus earn zero profits. B will always be better off delaying its launch and earning non-zero profits at a later date. Note that the greater B's development lead (t_A), the greater must A's quality advantage (k) be to force B to delay launch (since k must be greater than $1/\delta^{t_A}$ which is increasing in t_A). In the intermediate case where A's quality advantage is such that $k\delta^{t_A} < 1 < k\delta$, B will immediately enter the market as the only seller but will drop out in time period τ defined by $k\delta^{t_A-\tau+1} < 1 < k\delta^{t_A-\tau}$. There will be no firm in the market from τ until A enters in period t_A. B will reenter in period $t_B \ge t^A$, in line with Corollary 3.

The following proposition establishes the cost advantage B requires to prevent A from entering the market at all.

PROPOSITION 2

Firm B must have a cost advantage $c_B < c_A - (k-1)$ before it can profitably prevent A from entering the market.

Proof: See Appendix.

Formal Specification of the Model

To focus on the firms' price discrimination and competition motives we assume constant marginal cost for each firm and $c_A \geq c_B$. We further assume that the customers and the firms share a common discount factor δ.[7] The game between the firms can be specified more formally as follows. Noting that we seek a subgame perfect equilibrium, the firms' optimizing problem can be expressed as a dynamic program. For a more detailed explanation of this approach in the monopoly case, see Besanko and Winston (1990). Our model extends the problem to a duopoly. We first specify the problem when customers are nonmyopic (with rational expectations). There are two cases here, as discussed, depending on whether or not $k\delta < 1$. We then specify the problem when customers are myopic (with zero foresight).

Nonmyopic Case I: $\delta k < 1$

$$\pi_{At} = \max_{p_{At}} (p_{At} - c_A) D_{At} + \delta \pi_{At+1}, \tag{13.}$$

$$\pi_{Bt} = \max_{p_{Bt}} (p_{Bt} - c_B) D_{Bt} + \delta \pi_{Bt+1}, \tag{14.}$$

where π_{At} (π_{Bt}) represents the optimal discounted profits for A (B) over the periods (t, t+1, ..., T) and

$$D_{At} = \hat{\phi}_{t-1} - \overline{\phi}_t \tag{15.}$$

$$\text{and } D_{Bt} = \overline{\phi}_t - \hat{\phi}_t, \tag{16.}$$

and the boundary reservation prices, $\hat{\phi}_t$ and $\overline{\phi}_t$, for the demand equations, D_{it}, defined by the following constraints:

$$\overline{\phi}_t k - p_{At} = \overline{\phi}_t - p_{Bt} \tag{17.}$$

$$\hat{\phi}_t - p_{Bt} = \delta\left(\hat{\phi}_t k - p_{At}\right) \tag{18.}$$

Nonmyopic Case II: $\delta k \geq 1$

Similarily, the case where $\delta k \geq 1$ can be described as follows:

$$\pi_{At} = \max_{p_{At}} (p_{At} - c_A) D_{At} + \delta \pi_{At+1}, \tag{19.}$$

[7] Technically, this assumption would hold exactly if capital markets were perfect.

$$\pi_{Bt} = \begin{cases} \delta\pi_{Bt+1} & t < t^A \\ \max\limits_{p_{Bt}}(p_{Bt} - c_B)D_{Bt} + \delta\pi_{Bt+1} & t \geq t^A \end{cases} \tag{20.}$$

where t^A is the last period in which A makes any sales, and where

$$D_{At} = \begin{cases} \hat{\phi}_{t-1} - \hat{\phi}_t & t < t^A \\ \hat{\phi}_{t-1} - \overline{\phi}_t & t = t^A \\ 0 & t > t^A \end{cases}, \tag{21.}$$

$$D_{At} = \begin{cases} 0 & t < t^A \\ \overline{\phi}_t - \hat{\phi}_t & t = t^A \\ \hat{\phi}_{t-1} - \hat{\phi}_t & t > t^A \end{cases}, \tag{22.}$$

and the boundary reservation prices are defined as follows:

$$\hat{\phi}_t k - p_{At} = \delta\left(\hat{\phi}_t k - p_{At+1}\right) \quad t < t^A, \tag{23.}$$

$$\hat{\phi}_t - p_{Bt} = \delta\left(\hat{\phi}_t - p_{Bt+1}\right) \quad t \geq t^A, \tag{24.}$$

and $$\overline{\phi}_{t^A} - p_{Bt^A} = \overline{\phi}_{t^A} k - p_{At^A} \quad t = t^A. \tag{25.}$$

Myopic

In the case of myopic customers, the problem is:

$$\pi_{At} = \max_{p_{At}}(p_{At} - c_A)D_{At} + \delta\pi_{At+1}, \tag{26.}$$

$$\pi_{Bt} = \max_{p_{Bt}}(p_{Bt} - c_B)D_{Bt} + \delta\pi_{Bt+1}, \tag{27.}$$

where $D_{At} = \hat{\phi}_{t-1} - \overline{\phi}_t$ and $D_{Bt} = \overline{\phi}_t - \hat{\phi}_t$, and the boundary reservation prices, $\hat{\phi}_t$ and $\overline{\phi}_t$, for the demand equations, D_{it}, are defined by the following constraints:

$$\overline{\phi}_t k - p_{At} = \overline{\phi}_t - p_{Bt} \tag{28.}$$

$$\overline{\phi}_t - p_{Bt} = 0 \tag{29.}$$

The analytical solution to these games are very complex and difficult to interpret. In the following section we use simulation analysis to examine the impact of the model's structural parameters on the equilibria in a five period horizon.

4. Simulation Analysis

In this section we investigate the effects of customer foresight (myopic vs. nonmyopic, with perfect foresight), quality and cost differences (k and c_A - c_B), as well as the discount factor (δ) on the equilibrium (price paths, market penetration, and profits) in a multiperiod horizon. We employ simulation analysis, which allows us to explore the impact of the model's structural parameters, δ, c_A, c_B, and k on the complex analytical solution. Given our primary interest in contrasting the myopic and perfect foresight cases under different conditions, we examine in particular the interactive effects of the structural parameters with customer foresight. Further, in order to appreciate the implications of customer foresight for market power, we add a competitive market structure variable (monopoly vs. duopoly).

A quasi-numerical procedure is used for the simulation analysis.[8] The procedure calculates the optimal values of the price paths, cumulative penetration path, consumer and producer surpluses, and profits. The following range of values are used for the model's parameters in the simulation:

1. $\delta = 0.5$, 0.7 and 0.9 (low, medium, and high discount factors).
2. $k = 1.1$, 1.3 and 1.5 (low, medium, and high quality advantage for A).
3. $c_A = 0$, 0.1 and 0.5, $c_B = 0$ (no, low, and high cost advantage for B).[9]

Values of k beyond 1.5 represent an overwhelming quality advantage for A, swamping any interesting price dynamics in the competition between the firms. Similarly, values of $c = c_A - c_B$ greater than 0.5 result in an overwhelming cost advantage to firm B. We fix the planning horizon, T, at five periods; extending the horizon provides little additional insight as most of the interesting price competition takes place within five periods. Also, as before, we assume that the customer reservation price for B, ϕ, is distributed U[0,1]. While we carried out our simulation analysis using a "full factorial" design, we report the results selectively, focusing on the important and interesting effects.

[8] The procedure was programmed using the software package Mathematica. Mathematica is a symbol manipulation package that allowed us to program the procedure in a highly efficient and accurate manner.

[9] Without loss of generality, c_B is set equal to zero.

Customer Foresight and Structural Variables

Table 1 presents the optimal profits and price paths (as summarized by the average percentage change in price while the product is on the market), for the equal cost ($c = c_A - c_B = 0$) situation, focusing on the effects of customer foresight (myopic vs. nonmyopic), the quality parameter k, and the discount factor δ, in a duopoly. Figures 2 and 3 plot the price and cumulative market penetration (for both brands combined) paths respectively to contrast the myopic and nonmyopic cases for low and high quality differentials, given a duopoly with equal cost and $\delta = 0.9$.

Customer foresight effects. When the customers are nonmyopic, the future price strategies of the firms influence the outcome of the current price competition. That is, because nonmyopic customers are able to predict the future prices the firms will offer correctly, they are able to use this information in conjunction with the current prices to determine their adoption decisions. Thus, in setting their current prices, the firms must not only consider the consequences of the future period prices and profits (a result of their own nonmyopic behavior) but they must also consider the impact of those future prices on customers' adoption decisions today.

Comparing the myopic and nonmyopic cases in Table 1 (for any combination of δ and k), we note that *the total discounted profits and initial (period one) prices are always lower, while percentage price changes are uniformly less negative in the case of nonmyopic customers.* This result for our duopoly model corresponds to that for the monopoly situation (Besanko and Winston 1990) and reflects the impact of customer foresight on market power. The effect of customer foresight on the price path is graphically illustrated in Figure 2, by the lower initial prices and less steep price paths for the nonmyopic cases (except when $\delta k > 1$).

The exception when $\delta k > 1$ is an interesting interaction between customers' future expectations and the price competition between the two firms. As discussed in Section 3, for $\delta k > 1$ (and $c_A = c_B$), B delays entry of its lower quality brand until the final period. For $\delta k > 1$ customers gain more by waiting a period and buying the higher quality brand than they lose from delayed consumption. Thus in Table 1, for $\delta = 0.9$ and $k = 1.3$ and 1.5, and $\delta = 0.7$ and $k = 1.5$ we see B entering the market only in the final period. In Figures 2 and 3, the resulting lack of competition is evidenced by the higher price path (Figure 2) and slower penetration (Figure 3) characteristic of a monopoly, for the case δ

= 0.9 and k = 1.5. When $\delta k < 1$, the price competition in a duopoly reduces much of potential benefits from intertemporal price discrimination. Any customers that are left for future periods must be shared with the competition; hence the rapid penetration of the finite market that we observe in the duopoly case.

Comparing the cumulative penetration paths for the myopic and nonmyopic customer cases in Figure 3, we note that *the penetration rate is slower in the case of nonmyopic customers.* This is a result of customers' future price and product expectations. Nonmyopic customers anticipate the imminent price decreases and tend to delay their purchases. Similarly, customers considering adopting B compare the surplus from buying B in the current period with waiting and buying the higher quality A in the next period. Both of these factors contribute to the reduction in the penetration rate for the case of nonmyopic customers. In response to this behavior, *the firms tend to reduce their initial prices and lower them more slowly over time compared to the case of myopic customers* (see Figure 3).

Quality effects. It can be seen from Table 1 (and Figure 2) that *as k increases, the initial (first period) prices increase for both A and B. Also, the slope of the price paths, in terms of the average percentage price change, becomes less negative as k increases* (note the absolute price change can actually increase but the percentage change always decreases). Figure 3 shows that *as k increases the degree of penetration at any point in time decreases, for both the myopic and nonmyopic cases.*

Increasing k implies increasing quality differentiation which decreases the degree of competition between the firms. Observe from Table 1 that, *for both myopic and nonmyopic ($\delta k < 1$) cases, the total discounted profits increase with k, not only for A but for B as well,* despite the fact that increasing k implies increasing quality advantage for A. Notice, however, that the positive impact of k on profits is of greater magnitude for A than it is B. Further, the increase in profits for B is smaller when customers are nonmyopic *($\delta k < 1$). For the nonmyopic case, profits for B increase in k until $\delta k = 1$, at which point there is a discontinuous drop (as B does not enter the market until the final period). Thereafter (with $\delta k > 1$), B's profits are again increasing in k.*

Discount factor effects. Table 1 shows that changes in the discount factor d have a smaller impact than do changes in k. *In the case of myopic customers, the discount factor affects only the manner in which the firms value future profits. As δ decreases* *(i.e., the discount rate increases), total discounted profits will decrease*; however, because most of the sales tend to take place in the early periods in our example, very little change in profits or price paths is evident.[10] *For the nonmyopic case, δ also affects the customers purchase decision and, in general (for $\delta k < 1$), we see increasing profits for the firms as δ decreases.* Now, the negative effect of a decrease in the discount factor on the firm's total discounted profits is more than compensated by the positive effect of the customers' more myopic behavior resulting from discounting to a greater degree.

The exception to this pattern occurs when δk switches between greater and less than one, in which case the degree of competition effectively changes, as discussed. For example, for $k = 1.5$, A's total discounted profits decline as δ decreases from 0.9 to 0.5. In the case of $\delta = 0.9$, $\delta k > 1$, and A enjoys a near monopoly while for $\delta = 0.5$, $\delta k < 1$, duopoly conditions prevail (see Figure 4).

Cost Differential. So far in this section, we have considered that the firms have equal costs. We now examine the situation where the firm with the lower quality brand has a cost advantage. That is, we assume firm A has only been able to achieve a higher relative quality position by increasing its marginal cost. While in some circumstances it is possible for firms to increase their quality at zero cost through improved quality management (Garvin 1988), we now focus on the case where higher quality has been achieved via improved features, performance, capacity, etc. Thus we are using the term quality in its broader context.

The introduction of a cost differential results in a number of interesting implications for the firms' pricing strategies. In particular, firm B, which suffers from a quality disadvantage, now has a cost advantage which it can exploit by maintaining profitability at lower prices than can firm A. Thus we can expect that it will be more difficult for A to push B out of the market. Indeed, if B's cost advantage is sufficiently large it may prove profitable for firm B to force A out of the market (see Proposition 2).

Table 2 presents the optimal profits and price paths (as summarized by the average percentage change in price while the product is on the market). The cost differential c_A - c_B is denoted by c. The main effect of the cost advantage for B can be seen by

[10] The results presented in Table 1 are rounded to two and three significant digits and thus do not reflect the very small changes.

comparing the results in Table 2 to those in the equal cost case in Table 1. *As c increases, firm A is priced out of the market completely in progressively earlier periods until for a sufficiently high cost, it is excluded altogether* (see the case with $c = 0.5$ and $k = 1.1$). Note that while the result that a strong quality advantage for A might keep B out of the market for several periods giving A near monopoly status requires nonmyopic consumers, *the effect of a strong cost advantage for B in forcing A out of the market does not require customer foresight. Indeed, there may be situations* (for example, see Table 2, $c = 0.1$, $k = 1.5$, $\delta = 0.9$) *where A's quality advantage keeps B out of the market in the early periods if the customers are nonmyopic, while B's cost advantage forces A out early if the customers are myopic, resulting in greater discounted profits for A in a market with nonmyopic customers!* (In our example, A is forced from the market after the first period in the case of myopic customers, whereas in the case of nonmyopic customers, A is able to make sales throughout the planning horizon by keeping B out until the final period.)

Effect of Customer Foresight on Market Power: Monopoly Versus Duopoly Markets

We compare the impact of customers' future expectations across the monopoly and duopoly markets by examining the relative distribution of the consumer and producer surplus.[11] Figure 5 shows how the total surplus is shared among the firm(s) and the customers in monopoly and duopoly markets, for selected values of model parameters. *The main effect of the price competition introduced in the duopoly is that customers gain a uniformly larger share of the total surplus.* As we would expect, customers are considerably better off when there is price competition. Similarly, *the main effect of customer foresight is that in both the monopoly and duopoly situations customers are always better off when they are nonmyopic* (at least as long as $\delta k < 1$).

More interesting than these expected main effects is the *interaction* between customer foresight and price competition. The impact of customer foresight, as measured by the relative change in the customers' share of the total surplus, is considerably less when there is any price competition. For example, for $\delta = 0.5$ and $k = 1.1$, in the monopoly case, foresight improves the customers' share of the total surplus from 26% to 47%, and in the case of the duopoly there is almost no change at a 91% share. *Thus with price competition, the impact of customer foresight on market power is considerably reduced.*

[11] For the monopoly results firm B was assumed to have withdrawn from the market completely.

An example of what can happen when $\delta k > 1$ is provided by the case $\delta = 0.9$ and $k = 1.5$. While the consumers' proportion of the total surplus remains almost constant, (actually it increases very slightly), there is a decrease in the absolute amount of consumer surplus for the case of nonmyopic (relative to myopic) customers. As discussed previously, the customers' foresight enables firm A to force firm B from the market until the last period. This returns the market to a near monopoly with an accompanying decrease in cumulative penetration and total surplus. In other words, *there may be situations (when $\delta k > 1$) in which in the finite time horizon game, the customers are collectively worse off if they are sophisticated and behave strategically than if they are myopic*!

Figure 5 focuses on the equal cost case. The impact of a cost advantage for B is as expected: *As B's cost advantage increases, B is able to appropriate a larger portion of the total producer surplus. Further, in circumstances where B is able to use its advantage to force A from the market altogether, it is able to appropriate a large proportion of the consumer surplus as well.* (For example, for $k = 1.1$, $\delta = 0.9$ and myopic customers, as the cost difference c increases from 0.1 to 0.5, the percentage surplus B appropriates increases from 8% to 54% while A's proportion is reduced from 2% to 0% and the consumer surplus is reduced from 86% to 46%.)

5. Conclusion

We have examined the implications of buyers' price expectations on market evolution and pricing in a duopoly setting. Customers are assumed to formed rational expectations and make their adoption decision and brand choice simultaneously. The two firms market differentiated products, with brand A of higher quality (and thus more preferred) than B, and possibly higher unit cost.

An important result is given by Proposition 1 and its Corollary 1: *In equilibrium, customers always adopt in descending order of reservation price.* This result is a consequence of customers' rational expectations and the firms' pricing behavior. The result is straightforward for situations where $\delta k < 1$. The firms share the market in each period with the high quality brand A taking the customers with the higher reservation prices. However, when $\delta k \geq 1$ A's quality advantage is such that customers gain more by waiting a period and buying brand A than by buying brand B immediately ($\phi k \delta > \phi$). As a result, B delays the entry of its product into the market until later periods, thus turning over the high reservation price segment completely to A. This reduces the price competition between the firms, increasing profits for A, and maintaining a residual market for B. The case of $\delta k \geq 1$ is perhaps the most striking illustration of the impact of customers' future expectations on the competition between the firms.

We used quasi-numerical simulation analysis in a five period planning horizon to examine the impact of the quality advantage k, discount factor δ and A's cost disadvantage c on the equilibrium. The general effects of customer foresight are intuitively appealing. *Relative to the case of myopic customers, firm profits tend to decrease, initial prices are lower and the slope of the price path is less negative when the customers are nonmyopic.* Also the rate of market penetration is slower. Again, the important exception is the withdrawal of B when $\delta k > 1$ in which case A's profit can actually be greater in the case of nonmyopic customers. This is a consequence of the advantage A is able to secure because of customers' foresight and willingness to wait. The main effect of increasing the quality differential k is intuitive, *Brand A becomes more preferred over B, the differentiation between the products increases and profits for both firms increase. However, if k increases to the point that $\delta k \geq 1$ and the customers are nonmyopic, the profits for B actually decrease.* The effect on the price paths is mixed. *In the case of equal costs, increasing k results in higher initial prices with less steep decreases over time.* However, when A has a cost disadvantage there is a segment of the market, consisting of customers with low reservation prices, that B can serve more profitably than A. In general, at some point in the horizon only these customers remain to adopt and B begins to price as a monopolist with correspondingly less aggressive pricing. Initial prices still increase with k regardless of the relative cost positions of the firms.

The effect of changes in the discount factor is different for the myopic and nonmyopic cases. In both cases decreasing δ decreases the value of future profits to the firms. However, in addition to this effect in the case of nonmyopic customers, decreases in the discount factor reduce the impact of future expectations in the adoption decision. This latter effect dominates the decrease in the firms' valuation of future profits. Consequently, *in the case of myopic customers decreases in δ tend to decrease total discounted profits, while in the case of nonmyopic customers, profits tend to increase.* The exception to this result for nonmyopic customers follows from changes in the $\delta k > 1$ condition. As δ decreases and δk switches from greater than to less than one, profits for A decrease but increase for B.

We also note that the relative impact of customers' expectations is considerably greater in the case of a monopoly than in a duopoly. This is largely a consequence of the competition between the two firms in the duopoly driving prices down regardless of customers' expectations. We also have the curious anomaly (for $\delta k > 1$) where the collective consumer surplus may actually be lower when customers have foresight, because of A's virtual monopoly status.

Limitations and Directions for Future Research

Our objective was to isolate and examine the effects of customers' future expectations and price competition. Our stylized model did not include the impact of factors such as awareness, uncertainty, etc., that tend to slow the adoption rate in practice.

Uncertainty and Future Expectations. The deterministic setting of our model does not allow incorporation of uncertainty reduction via information acquisition, and its impact on reservation prices (Chatterjee and Eliashberg 1990). Incorporating information effects would require a different modeling approach, perhaps one that relaxes the rational expectations assumption and employs (for example) a Bayesian learning framework. Given the importance of learning in the new product diffusion process, this is an important and potentially fruitful research area.

Empirical Validation. Two basic approaches to empirical validation or testing of the nature and effect of future expectations are possible: experimentation and tests based on secondary data. An example of the second approach is Yoo, Dolan, and Rangan (1987). Experimentation allows the isolation and manipulation of factors of interest. Unfortunately, it is not possible from actual adoption behavior to disentangle the effects of the quality of a customer's forecast, the effective discount factor, and the customer's ability to combine these in making the adoption decision. Some type of multistage experiment is probably the best approach.

Model Extensions. The model can be extended by relaxing assumptions such as homogeneity with respect to the discount factor (i.e., different customers discount the future differently), the uniform distribution of customers' reservation prices (to examine the impact of different distributions), and the constant ratio (k) of the reservation price for the high quality brand to that for the basic model across the population. The value of these extensions will, of course, have to be judged against the increased complexity.

In conclusion, our modeling approach has attempted to balance richness and tractability in capturing the essential impact of customers' future expectations on market evolution in a duopoly with differentiated products, with the objective of providing some new insights into an important and hitherto unresearched problem.

Appendix

Proof of Proposition 1

The proof is in two parts. In the first part we show that when $\delta k > 1$the adoption order must be of the form:

$$A_1 A_2 \ldots A_\tau B_\tau B_{\tau+1} \ldots B_T$$

To see this, assume that it wasn't true, as illustrated by Figure A1:

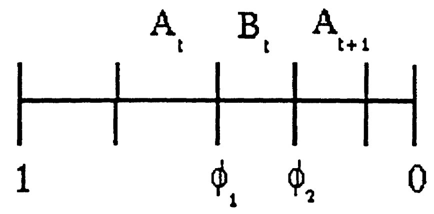

Figure A1

The condition for adoption for the customers $\phi_1 - \phi_2$ is:

$$\phi - p_{B2} \geq \delta(\phi k - p_{At+1})$$

and boundary condition for ϕ_2 is:

$$\phi_2 - p_{B2} = \delta(\phi_2 k - p_{At+1}) \quad \text{(A1)}$$

$$\phi_2(1 - \delta k) = p_{B2} - p_{At+1} \quad \text{(A2)}$$

Thus, because $1 - \delta k < 0$ any ϕ, $\phi_1 < \phi \leq \phi_2$, will prefer to delay adoption and adopt A in period t+1. To see that B cannot sell to the lower price segment until the last period that A makes any sales, assume that it wasn't true and B begins selling to the lower reservation price customers in period $t < \tau$. The situation is illustrated in Figure A2.

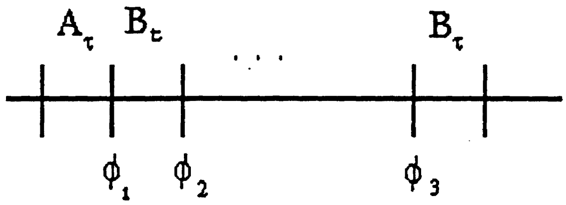

Figure A2

$$(\phi_1 k - p_{A\tau})\delta^{\tau - t + 1} = \phi_1 - p_{Bt}, \quad \text{(A3)}$$

$$(\phi_2 - p_{Bt}) = (\phi_2 - p_{B\tau})\delta^{\tau - t + 1}, \quad \text{(A4)}$$

$$\left(\phi_1 k - p_{A\tau}\right) = \phi_1 - p_{B\tau}. \tag{A5}$$

Conditions (A3) and (A4) are a result of the customers' rational expectations and condition (A5) is a result of firm A's profit maximization. Rearranging A5 and A3 yields:

$$\phi_1 - p_{Bt} = \delta^{\tau-t+1}\left(\phi_1 - p_{B\tau}\right). \tag{A6}$$

Noting that $\phi_1 \geq \phi_2$, (A6) and (A4) imply that $\phi_1 = \phi_2$. Moreover, it is clear that this will hold for all t, $1 \leq t < \tau$.

Proof of Corollary 1

The form of the intertemporal constraints ensures that higher reservation prices customers adopt no later than lower reservations price customers. For the customers adopting A these constraints are as follows:

$$\hat{\phi}k - p_{At} \geq \delta\left(\hat{\phi}k - p_{At+1}\right) \tag{A7}$$

$$\hat{\phi}k - p_{At} \geq \delta\left(\hat{\phi} - p_{Bt+1}\right) \tag{A8}$$

Clearly these constraints will hold for any $\phi \geq \hat{\phi}$. Thus if $\hat{\phi}$ adopts A in period t then any $\phi \geq \hat{\phi}$ who has not yet adopted will also adopt A in period t. For B we need to consider two cases. First for $\delta k \leq 1$ the intemporal conditions for the customers adopting B are:

$$\hat{\phi} - p_{Bt} \geq \delta\left(\hat{\phi}k - p_{At+1}\right), \tag{A9}$$

$$\hat{\phi} - p_{Bt} \geq \delta\left(\hat{\phi} - p_{Bt+1}\right), \tag{A10}$$

which will hold for any $\phi \geq \hat{\phi}$. Secondly, for $\delta k > 1$ we note that (A9) will not be satisfied for $\phi \geq \hat{\phi}$. However, from Proposition 1 we know that B is never sold in any periods in which A makes sales in the following period and thus only condition (A10) needs to be satisfiedwhen $\phi \geq \hat{\phi}$. Thus, any $\phi \geq \hat{\phi}$ who has not yet adopted and does not adopt A, will also adopt B in period t.

Proof of Corollary 2

It follows from Firm A's objective function that it will have an incentive to sell in every period and thus B will have to force A from market by offering a very low price. We establish that B cannot offer such a low price. Firm A's objective (in a dynamic programming framework) is:

$$\pi_{At} = \max_{p_{At}} \left(p_{At} - c_A\right) D_{At}\left(p_{At}, p_{Bt}\right) + \delta\pi_{At+1} \qquad \text{(A10)}$$

where π_{At} is the net present value of A's profits from period t until the end of the planning horizon, p_{At}, p_{Bt} are the prices of A and B in period t, c_A is A's cost of production and $D_{At}\left(p_{At}, p_{Bt}\right)$ is the quantity sold by A in period t.

If $\hat{\phi}_{t-1}$ is the customer with the highest reservation price who has not yet adopted then $D_{At}\left(p_{At}, p_{Bt}\right)$ is defined by:

$$D_{At}\left(p_{At}, p_{Bt}\right) = \hat{\phi}_{t-1} - \overline{\phi}_t, \qquad \text{(A11)}$$

where $\overline{\phi}_t$ is the customer with the lowest reservation price who adopts A in period t. This customer is defined by the following condition:

$$\overline{\phi}_t k - p_{At} = \overline{\phi}_t - p_{Bt}. \qquad \text{(A12)}$$

For B to force A from the market it must set a price p^*_{Bt} such that $\hat{\phi}_t = \overline{\phi}_t$, or:

$$\hat{\phi}_t k - p^*_{At} = \hat{\phi}_t - p^*_{Bt} \qquad \text{(A13)}$$

Assume that B chooses its lowest possible price $p^*_{Bt} = c_B$, substituting into (A13) and rearranging:

$$p^*_{At} = \hat{\phi}_t(k-1) + c_B. \qquad \text{(A14)}$$

Because $\hat{\phi}_t(k-1) > 0$ and $c_A = c_B$ A can always profitably set a price lower than p^*_{At} and thus $D_{At}\left(p_{At}, p_{Bt}\right) > 0$, $\forall t, 1 \le t \le T$, where T is the final period of the finite period game. Because A is making sales in every period we know from Proposition 1 that B cannot enter until the final period of the game. To see that B can always enter the market in the final period note that the intertemporal constraints that need to be satisfied are simply:

$$\phi k - p_{AT} \ge 0 \text{ and } \phi - p_{BT} \ge 0. \qquad \text{(A15)}$$

Proof of Corollary 3

From Proposition 1 we know that if the adoption pattern is:

$$A_1 A_2 \ldots A_\tau B_\tau B_{\tau+1} \ldots B_T$$

then B will not be able to enter until the final period that A makes any sales. Thus we need only to establish that B can not make any sales to high reservation value customers. Assume that the corollary wasn't true and B could sell to high reservation price customers in periods prior to A entering the market. Figure A3 illustrates the situation:

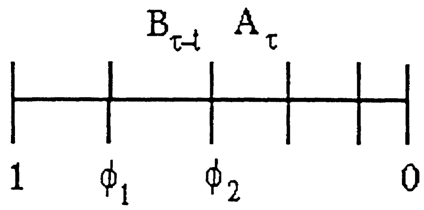

Figure A3

where $1 \leq t < \tau$. The condition for adoption for the customers $\phi_1 - \phi_2$ is:

$$\phi - p_{B\tau-t} \geq \delta^t(\phi k - p_{A\tau}), \tag{A16}$$

and the boundary condition for ϕ_2 is:

$$(\phi_2 - p_{B\tau-t}) = (\phi_2 k - p_{A\tau})\delta^t, \tag{A17}$$

Rearranging (A17):

$$\phi_2(1-\delta^t k) = p_{B\tau-t} - p_{A\tau} \tag{A18}$$

Because $1-\delta^t k < 0$ any ϕ, $\phi_1 < \phi \leq \phi_2$, will prefer to delay adoption and adopt A in period τ. This result holds $\forall t, 1 \leq t \leq \tau$. .

Proof of Proposition 2

Let ϕ_1 denote the highest reservation price customer to adopt B in period 1. If A is prevented from entering the market it must be prevented from making any sales in the first period and thus ϕ_1=1. The boundary condition for ϕ_1 is:

$$\phi_1 k - p_{A1} = \phi_1 - p_{B1}. \tag{A19}$$

rearranging and substituting ϕ_1=1and $p_{A1} = c_A$, A's lowest profitable price:

$$p_{B1} = c_A - (k-1). \tag{A20}$$

B can profitably price at or below this price iff:

$$c_B \leq c_A - (k-1). \tag{A21}$$

References

Ausubel, L., and R. Deneckere (1987), "One is Almost Enough for Monopoly," *Rand Journal of Economics*, 18, 255-274.

Bass, F. M. (1969), "A New Product Growth Model for Consumer Durables," *Management Science* 15, 215-227.

Besanko, D. and W. L. Winston (1990), "Optimal Price Skimming by a Monopolist Facing Rational Consumers," *Management Science*, 36, May, 555-567.

Bulow, J. (1986), "An Economic Theory of Planned Obsolescence," *Quarterly Journal of Economics* 51, 729-750.

Bulow, J. (1982), "Durable Goods Monopolists," *Journal of Political Economy* 15, 314-332.

Chatterjee, R. and J. Eliashberg (1990), "A Micromodeling Approach to The Innovation Diffusion Process in a Heterogeneous Population," *Management Science*, 36, September, 1057-1079.

Clarke, D. G. and R. J. Dolan (1984) "A Simulation Model for the Evolution of Pricing Strategies in a Dynamic Environment," *Journal of Business*, 57, (January) S179-S200.

Clarke, F, M. Darrough and J. Heineke (1982), "Optimal Pricing Policy in the Presence of Experience Effects," *Journal of Business*, 55, 4, 517-530.

Coase, R. H. (1972), "Durability and Monopoly," *Journal of Law and Economics* 15, 143-149.

Conlisk, J., E. Gerstner and J. Sobel (1984), "Cyclic Pricing by a Durable-Goods Monopolist," *Quarterly Journal of Economics* 99, 489-505.

Doyle, P. and J. Saunders (1985), "The Lead Effect of Marketing Decisions," *Journal of Marketing Research* 22, (February), 54-65.

Eliashberg, J. and A. P. Jeuland (1986), "The Impact of Competitive Entry in a Developing Market Upon Dynamic Pricing Strategies," *Marketing Science*, 5, (Winter), 20-36.

Elrod, T. and R. S. Winer (1983), "An Empirical Comparison of Aggregation Approaches for Developing Market Segments," *Journal of Marketing* 46, Fall, 65-74.

Garvin, D.A. (1988), *Strategic Quality Management,* Cambridge, MA: Harvard University Press.

Gul, F., H. Sonnenschein and R. Wilson (1986), "Foundations of Dynamic Monopoly and the Coase Conjecture," *Journal of Economic Theory* 39, 155-190.

Holak, S., D.R. Lehmann and F. Sultan (1987), "The Role of Expectations in the Adoption of Innovative Consumer Durables: Some Preliminary Evidence," *Journal of Retailing,* 63, (Fall), 243-59.

Kalish, S. (1983), "Monopolistic Pricing with Dynamic Demand and Production Cost," *Marketing Science* 2, 135-159.

Lambin, J. J. (1976), *Advertising, Competition and Market Conduct in Oligopoly Over Time,* Amsterdam: North Holland.

Levinthal, D. and D. Purohit (1989), "Durable Goods and Product Obsolescence," *Marketing Science* 8, 3 (Winter), 35-56.

Mahajan, V., E. Muller and F. M. Bass (1990), "New Product Diffusion Models in Marketing: A Review and Directions for Future Research," *Journal of Marketing,* 54 (January), 1-26.

Moorthy, K. S. (1988), "Consumer Expectations and the Pricing of Durables," in *Issues in Pricing: Theory and Research,* T. Devinney (ed.), Lexington, MA: Lexington Books, 99-114.

Narasimhan, C. (1989), "Incorporating Consumer Price Expectations in Diffusion Models," *Marketing Science,* 8, 4, (Fall), 343-357.

Patterson, (1990), "Ford Plans Incentives for October," *Wall Street Journal,* Wednesday, May 30.

Rao, R.C. and F.M. Bass (1987) "Competition, Strategy and Price Dynamics: A Theoretical and Empirical Investigation," *Journal of Marketing Research,* 22 (August), 283-296.

Selten, R. (1975), "Reexamination of the Perfectness Concept for Equilibrium Points in Extensive Games," *International Journal of Game Theory* 4, 25-55.

Stokey, N. (1981), "Rational Expectations and Durable Goods Pricing," *Bell Journal of Economics* 12, 112-128.

Stokey, N. (1979), "Intertemporal Price Discrimination," *Quarterly Journal of Economics* 93, 355-371.

Suslow, V. (1986), "Commitment and Monopoly Pricing in Durable Goods Models," *International Journal of Industrial Organization* 4, 451-460.

Thompson, G.L. and J.T. Teng (1984), "Optimal Pricing and Advertising for New Product Oligopoly Models," *Marketing Science* 3, 148-168.

Winer, R. (1985), "A Price Vector Model of Demand for Consumer Durables: Preliminary Developments," *Marketing Science*, Winter, 74-90.

Yoo, P., R. Dolan and V. Rangan (1987), "Dynamic Pricing Strategy for New Consumer Durables," *Zeitschrift für Betriebswirtschaft* 57 (October), 1024-1043.

TABLE 1

Profits and Average Price Changes for Duopoly: Equal Costs

		Myopic			Nonmyopic		
	$k=$	1.1	1.3	1.5	1.1	1.3	1.5
δ							
0.9	π_A*	0.042	0.116	0.182	0.032	0.131	0.175
	π_B	0.010	0.022	0.030	0.003	0.001	0.002
	p_{A1}	0.065	0.185	0.300	0.055	0.262	0.349
	p_{B1}	0.029	0.072	0.101	0.011	---	---
	Δ_{pA}	–99%	–95%	–92%	–86%	–32%	–26%
	Δ_{pB}	–99%	–95%	–92%	–88%	---	---
0.7	π_A	0.042	0.116	0.182	0.038	0.095	0.252
	π_B	0.010	0.022	0.030	0.007	0.009	0.000
	p_{A1}	0.065	0.185	0.300	0.061	0.167	0.503
	p_{B1}	0.029	0.072	0.101	0.022	0.035	---
	Δ_{pA}	–99%	–95%	–92%	–94%	–82%	–44%
	Δ_{pB}	–99%	–95%	–92%	–94%	–87%	---
0.5	π_A	0.042	0.115	0.181	0.040	0.104	0.160
	π_B	0.010	0.022	0.030	0.008	0.015	0.018
	p_{A1}	0.065	0.185	0.300	0.063	0.176	0.281
	p_{B1}	0.029	0.072	0.101	0.026	0.053	0.062
	Δ_{pA}	–99%	–95%	–93%	–96%	–91%	–83%
	Δ_{pB}	–99%	–95%	–93%	–97%	–92%	–88%

* π_A, π_B denote total discounted profits, p_{A1}, p_{B1} period 1 prices, and Δ_{pA}, Δ_{pB} average percentage change in prices, for A and B respectively.

TABLE 2

Duopoly Profits and Average Price Changes: Quality and Cost Differences

			Myopic		Nonmyopic	
	$k=$		1.1	1.5	1.1	1.5
	δ					
$c=0.1$	0.9	π_A*	0.009(1)**	0.135(1)	0.008(1)	0.138(5)
		π_B	0.039	0.046	0.036	0.006
		p_{A1}	0.131	0.361	0.128	0.411
		p_{B1}	0.061	0.121	0.057	---
		Δ_{pA}	−5%	−18%	−5%	−19%
		Δ_{pB}	−35%	−45%	−10%	---
	0.5	π_A	0.008(1)	0.135(1)	0.008(1)	0.118(2)
		π_B	0.038	0.045	0.036	0.033
		p_{A1}	0.129	0.361	0.128	0.344
		p_{B1}	0.059	0.121	0.057	0.087
		Δ_{pA}	−6%	−18%	−5%	−18%
		Δ_{pB}	−44%	−50%	−38%	−44%
$c=0.5$	0.9	π_A	---(0)	0.026(1)	---(0)	0.015(1)
		π_B	0.292	0.141	0.192	0.105
		p_{A1}	0.500	0.615	0.500	0.589
		p_{B1}	0.400	0.230	0.385	0.179
		Δ_{pA}	---	−5%	---	−4%
		Δ_{pB}	−35%	−35%	−10%	−10%
	0.5	π_A	---(0)	0.022(1)	---(0)	0.017(1)
		π_B	0.263	0.128	0.208	0.109
		p_{A1}	0.500	0.606	0.500	0.592
		p_{B1}	0.400	0.212	0.400	0.185
		Δ_{pA}	---	−4%	---	−4%
		Δ_{pB}	−44%	−43%	−38%	−38%

* π_A, π_B denote total discounted profits, p_{A1}, p_{B1} period 1 prices, and Δ_{pA}, Δ_{pB} average percentage change in prices, for A and B respectively.

** Numbers in parentheses indicate the last period in which A makes any sales; (0) indicates that A is completely shut out of the market.

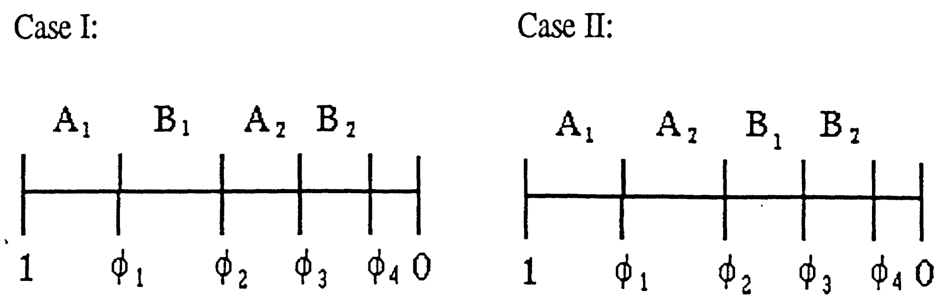

Figure 1
Adoption Patterns

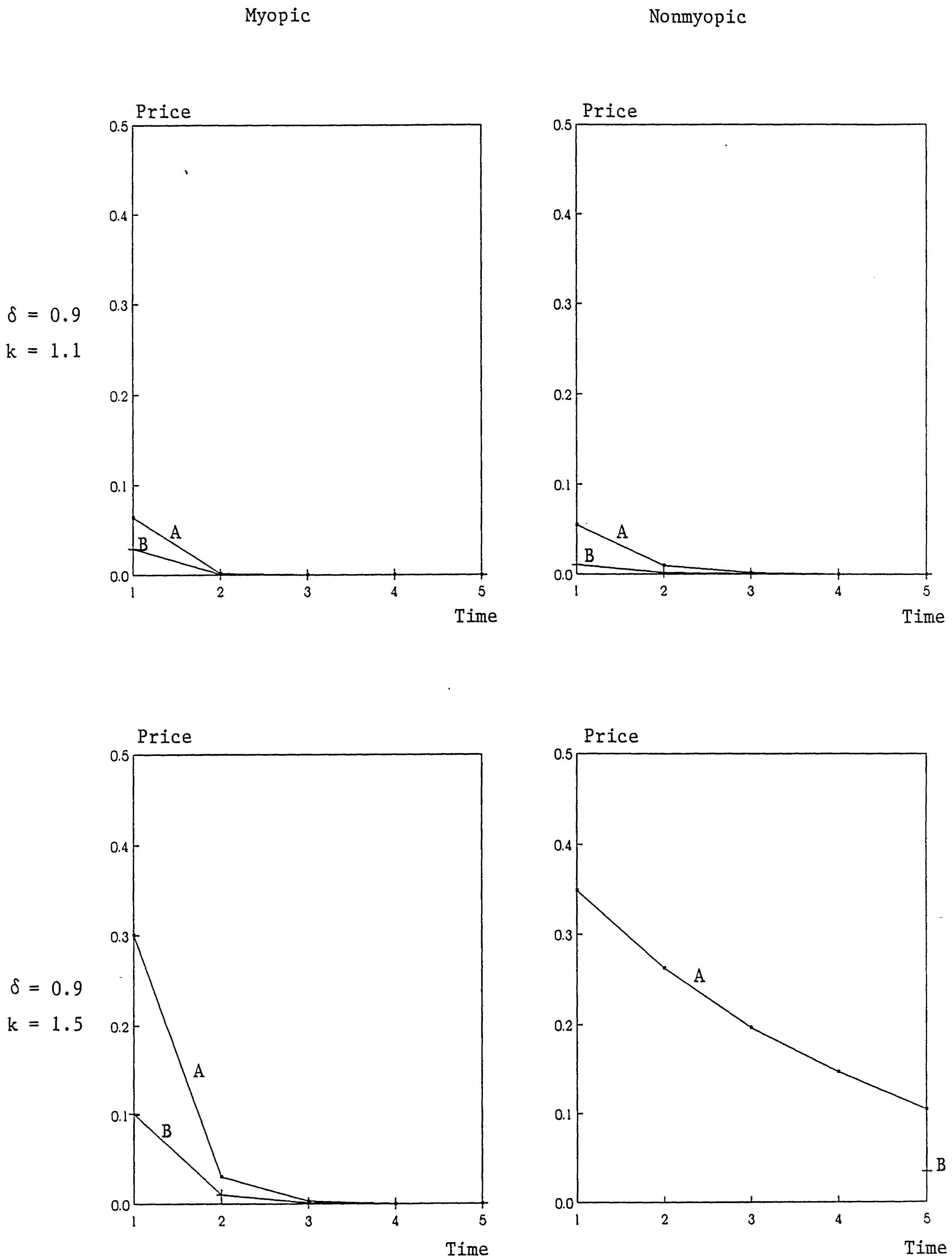

Figure 2

Optimal Price Paths: Equal Cost $\delta = 0.9$

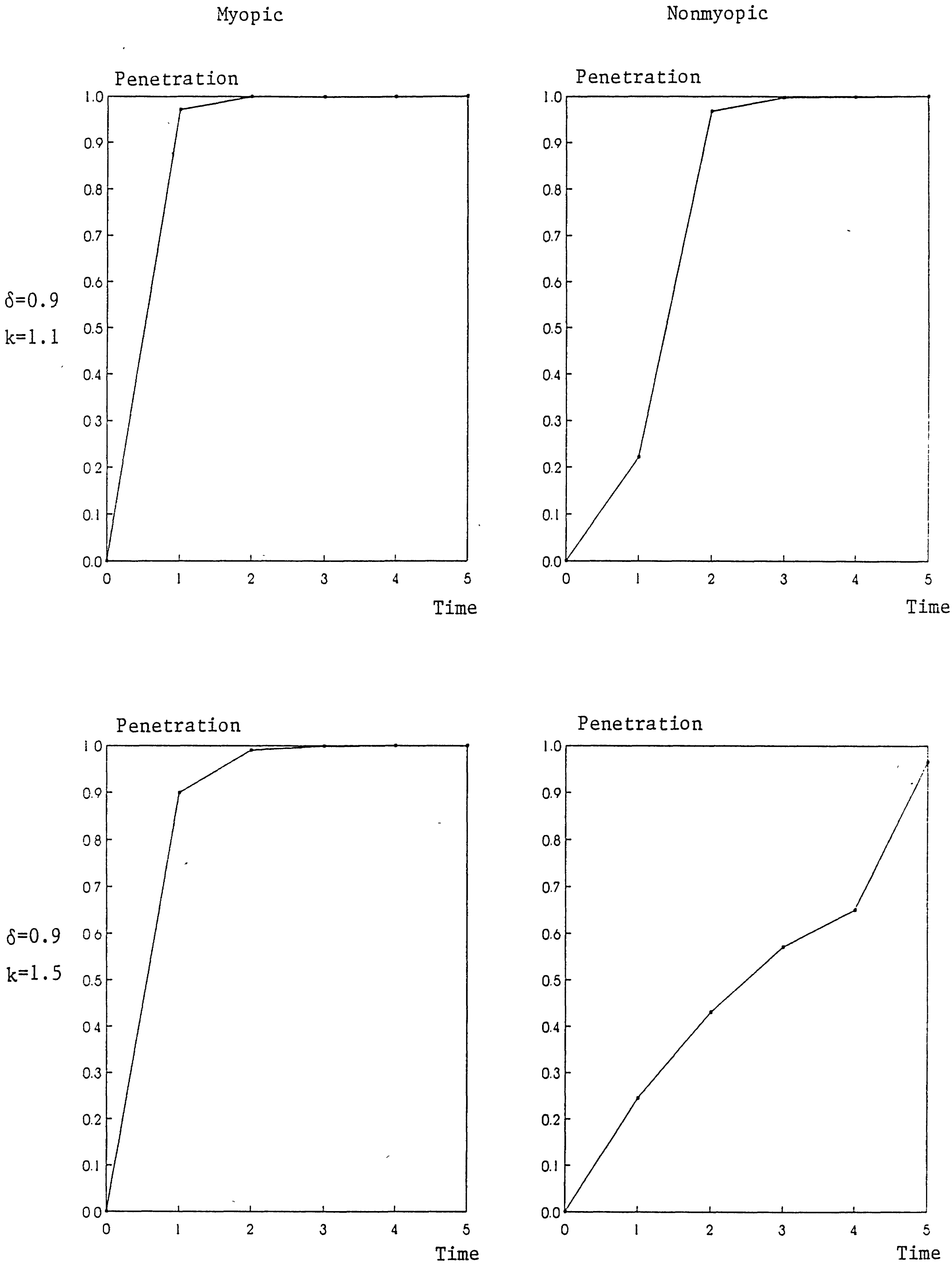

Figure 3

Cumulative Penetration Paths: Equal Cost $\delta=0.9$

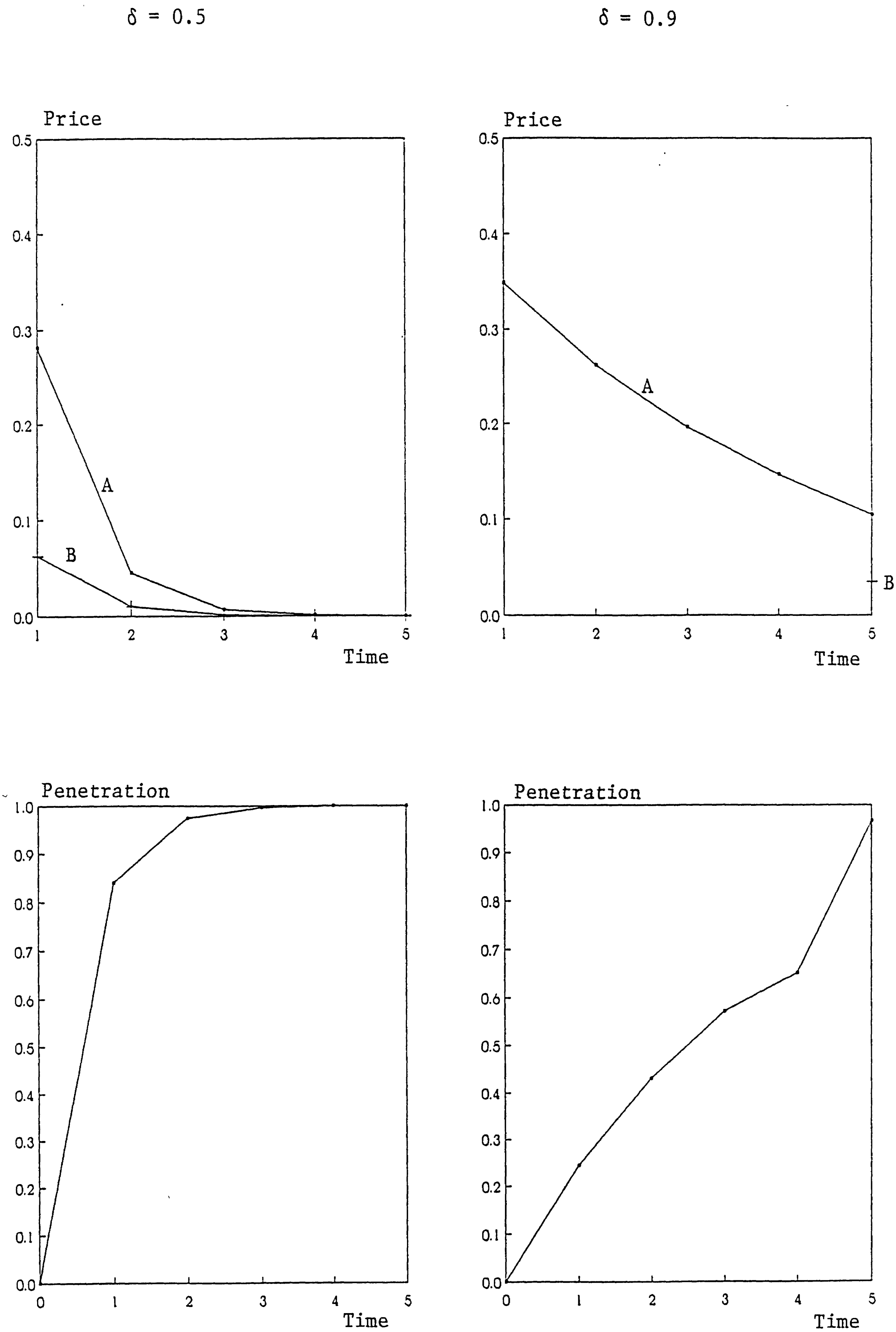

Figure 4

Price and Cumulative Penetration Paths: Nonmyopic Customers (k = 1.5)

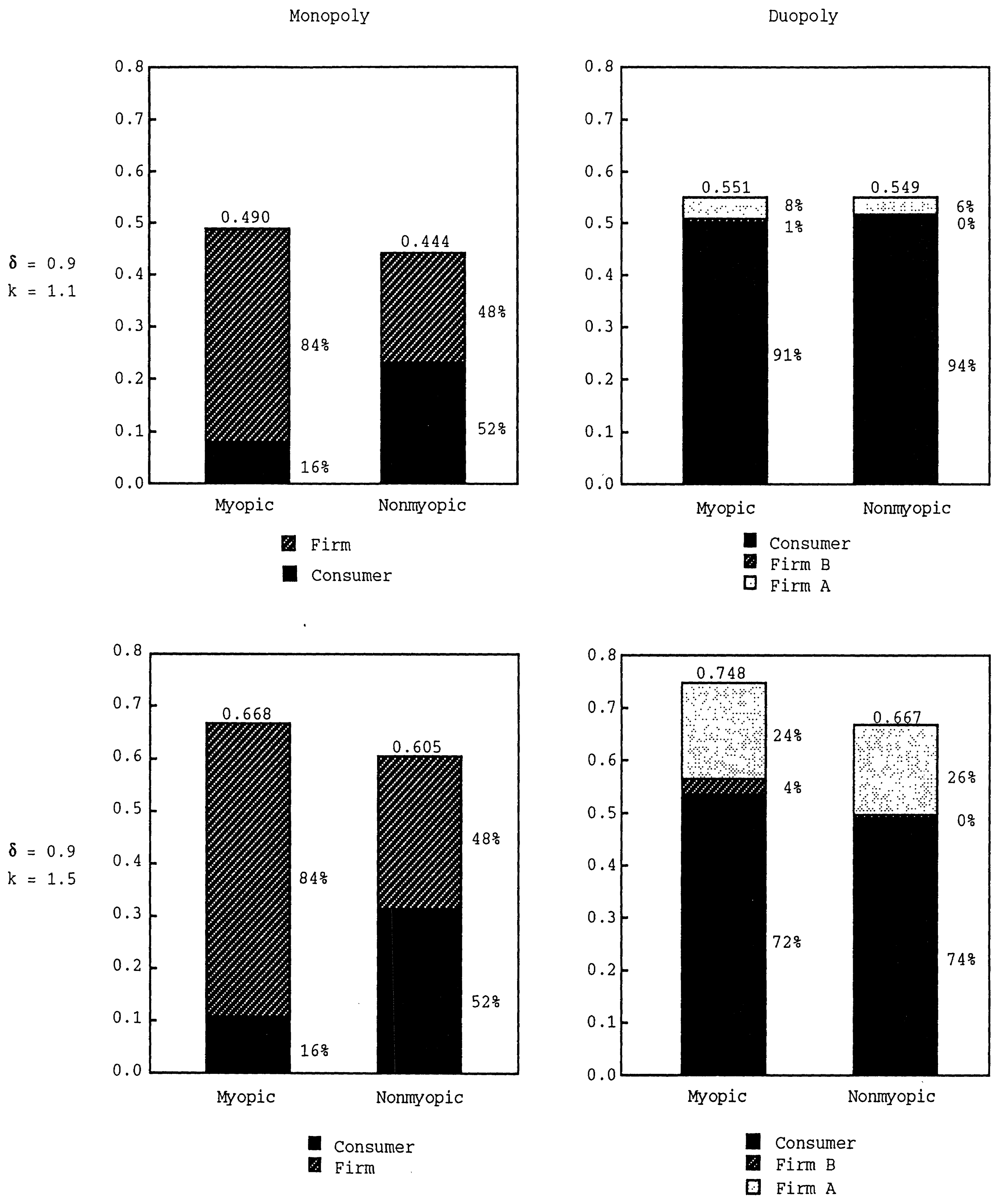

Figure 5

Consumer and Producer Surplus: Comparing Market Power