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High and Declining Prices Signal Product Quality

By KYLE BAGWELL AND MICHAEL H. RIORDAN *

High and declining prices signal a high-quality product. High prices are the efficient means of signaling, because the consequent loss of sales volume is most damaging for lower-cost, lower-quality products. As time passes and the number of informed consumers increases, the signaling distortion lessens, resulting in a declining price profile. The prediction of high and declining prices is robust across a variety of dynamic models and is consistent with recent empirical findings. (JEL 022, 026)

The marketing literature has produced various evidence on price-quality relationships. Numerous experimental studies show that consumers infer a higher quality from a higher price (Kent B. Monroe, 1973). This inference is consistent with the findings of several case studies. Such diverse products as fountain-pen ink and car wax (André Gabor and Clive Granger, 1965) and vodka, skis, and television sets (Robert D. Buzzell et al., 1972) have been successfully introduced at high prices to connote high quality. A variety of empirical data is also available. Analyses of *Consumer Reports* data yield positive price-quality rank-order correlations for many products, and particularly for consumer durables (Eitan Gerstner, 1985; Gerard J. Tellis and Birger Wernerfeld, 1987). Moreover, a recent longitudinal analysis of *Consumer Reports* data for consumer durables indicates declining trends in (a) real prices, (b) price differentials between competing brands, and (c) the rank-order correlation between price and

quality (David J. Curry and Peter C. Riesz, 1988).¹

These “stylized facts” are consistent with two important features of markets. First, firms signal high-quality new products with prices that are above full-information profit-maximizing prices. Second, over time, as information about the product diffuses, this price distortion lessens or vanishes entirely.

We demonstrate the logic and robustness of this argument in several equilibrium models of behavior by consumers and firms. The models have different assumptions about consumer information. However, all of the models possess intuitively plausible equilibria in which higher-quality products are introduced at higher prices that decline over time.

Our essential argument is outlined as follows. Consider a market in which a firm introduces a new product possessing some innovative feature of uncertain quality. Some consumers can ascertain the quality, while others cannot, but all understand that a higher-quality product is more costly to produce. The most efficient way for the firm to signal high quality is to charge a price too high to be profitable if the product were in fact of lower quality. This high-price strat-

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¹Curry and Riesz collected all test-study evaluations with five or more brands reported in *Consumer Reports* over a 20-year period. They retained only those durable products whose characteristics remained stable during at least three separate publication time periods.

egy is potentially successful for two reasons. First, the consequent loss of sales volume is less damaging to a higher-cost product. Second, a lower-quality product would lose more sales from informed consumers by charging a high price. Understanding this, uninformed consumers rationally infer higher quality from the higher price.

However, as consumers gain experience with the product and information about its quality diffuses, the portion of uninformed consumers in the market declines. Consequently, it becomes even more costly for the firm to signal a higher quality falsely to the uninformed. The firm can efficiently signal a higher quality with a smaller price distortion. Thus, a high and declining price path identifies a high-quality product.

A positive correlation between price and quality follows, because higher-quality products are more costly to produce, so that signaling distorts upward the price of newly introduced high-quality products. As information diffuses, signaling distortions diminish, and the prices of newer products converge downward to those of older products of corresponding quality. An associated weakening of the correlation between price and quality can then be explained by measurement errors in the data. Thus, the theory appears to be consistent with the stylized facts.

Our conclusion that high-quality products have a downward sloping price profile differs from that of previous theoretical contributions to the economics literature. For example, Carl Shapiro (1983) shows that a monopolist charges a high and declining price if consumers optimistically overestimate product quality and charges a low introductory price if consumers pessimistically underestimate product quality. However, these conclusions depend on an assumption that consumers have adaptive expectations about product quality with no possibility of price signaling.

Paul Milgrom and John Roberts (1986) focus on the introductory phase of a non-durable product's life and argue that prices will rise over time as repeat buyers learn about their own preferences. Their analysis is similar to ours in that they also recognize

the potential for high prices to signal high (expected) quality due to cost effects. However, we abstract from short-run experimental-buying effects and focus on the long-run trends associated with the signaling of product quality.²

In a dynamic model of consumer learning, Kenneth L. Judd and Riordan (1987) show that high-quality prices tend to rise after the introductory period. This is because signaling does not occur until after consumers have gained experience with the product, which follows from an assumption of cost parity for different-quality products. Moreover, they conjecture that, for multi-period extensions, price would eventually decline as consumers gain further experience.

John Conlisk et al. (1984) and Nancy L. Stokey (1981) have argued for a declining price path for a durable good of known quality. This path represents the firm's attempt to "skim" the market of higher-valuation buyers. Edward P. Lazear (1986) also predicts a declining price path, under the assumptions that the firm is unsure of the size of its demand and that consumers know quality. While these theories are complementary to ours, they do not provide direct insight into the relationships between price and quality described above.

Our distinction between informed and uninformed consumers is reminiscent of a related literature on product selection in which some consumers observe quality while others do not. In this context, Yuk-Shee Chan and Hayne Leland (1982), Russell Cooper and Thomas W. Ross (1984, 1985), Scott Davis (1989), Joseph Farrell (1980), Riordan (1986), and Asher Wolinsky (1983) argue that the presence of informed consumers enables high prices to signal high-

²This focus seems justified given the nature of the long-run data we seek to understand (see footnote 1). Further, introductory offers to inspire repeat purchases are less relevant for consumer durables than for non-durables, because of the infrequency of consumer purchases of durable goods. For other models of introductory offers and repeat purchases that focus on different issues, see Bagwell (1987), Jacques Crémer (1984), and Joseph Farrell (1986).

quality choices. While our work is related, we take quality to be exogenous and also analyze the role of production costs in establishing high prices as signals. Indeed, we find that high prices can signal high quality even if all consumers are uninformed. Informed consumers are not necessary for the signaling of a given quality, but they do determine the size of the signaling distortion.

Finally, we note independent work by Garey Ramey (1986) and Doron Fertig (1988). They analyze a static model with a continuum of types and no informed consumers and demonstrate a unique separating equilibrium in which high prices signal quality. Our model has only two cost-quality types, introduces informed consumers, and uses the "intuitive criterion" (In-Koo Cho and David M. Kreps, 1987) to select among equilibria. Ramey and Fertig do not develop predictions about the time path of prices.³

The paper is organized in three sections. Our basic results are developed in a static context in Section I. Various multiperiod extensions are analyzed in Section II. Sections I and II may have methodological interest. The intuitive criterion is actively employed in each section, and the criterion is applied in Section II to dynamic signaling games with the possibility of multiple dimensions of private information. Our conclusions are summarized in Section III.

I. Basic Model

Consider a one-period consumer market in which a firm has introduced a new product with a novel feature of uncertain quality. For simplicity, assume that quality is either high or low: $q \in \{H, L\}$.

The production technology is common knowledge. The average cost of a high-quality product is constant and equal to $c > 0$,

while low-quality production cost is normalized to zero without loss of generality.

There are many potential consumers of the new product, approximated by a continuum of mass M (Judd, 1985), each with a potential demand for one unit. Consumers have a common reservation price, $P^L > 0$, for a low-quality product. On the other hand, consumers have heterogeneous reservation prices for a high-quality product, uniformly distributed between P^L and $(1 + P^L)$. The uniform distribution is convenient because it generates a linear demand for a high-quality product.

Some consumers are informed about product quality, while remaining consumers believe that quality is high with probability r . This prior belief is common knowledge. Let X denote the ratio of informed to uninformed consumers.

At the beginning of the period, the firm and informed consumers observe the true quality of the product. The firm then sets a price P , and uninformed consumers update their beliefs about product quality on the basis of this signal. Let $b = b(P)$ be the uninformed consumers' posterior belief that quality is high when the price is P . Consumers are assumed to make purchase decisions that maximize expected utility (i.e., the expected reservation price minus P), given beliefs. This process generates an informed demand curve, in which a fraction $1 + P^L - P$ of informed consumers buy when $P \in [P^L, 1 + P^L]$ and $q = H$, and an uninformed demand curve, characterized by a fraction $1 + (P^L - P)/b$ of uninformed consumers buying when $P \in [P^L, b + P^L]$ and quality is believed to be high with probability b . With these demand curves and our assumptions on cost technologies, the profit of a firm with quality q and price P facing uninformed consumers with belief b , denoted $\pi(q, b, P)$, is straightforward to define explicitly.⁴ We assume that the objective of the firm is to maximize profits.

³Also, Jean Tirole (1988 Ch. 2) has a nice expository discussion of price as a signal of quality which refers to an earlier working paper (Bagwell and Riordan, 1986), which this article supersedes.

⁴For example, if $P \in (P^L, b + P^L)$, then $\pi(L, b, P) = P[1 + (P^L - P)/b]M/(1 + X)$ and $\pi(H, b, P) = (P - c)[(1 + P^L - P)X + (1 + (P^L - P)/b)]M/(1 + X)$.

These actions and objectives define an extensive-form game of incomplete information with multiple sequential equilibria (Kreps and Robert Wilson, 1982). A sequential equilibrium requires that the firm and consumers act in a sequentially rational fashion and that uninformed consumers update beliefs using Bayes' rule on the equilibrium path. As usual, we distinguish between separating equilibria (in which high- and low-quality firms choose different prices) and pooling equilibria. However, we do restrict attention to pure-strategy equilibria.

We select plausible equilibria by imposing the "intuitive criterion" (Cho and Kreps, 1987). Consider an equilibrium in which the firm earns profits of $\pi(H)$ and $\pi(L)$ for high- and low-quality products, respectively. Then the equilibrium satisfies the intuitive criterion if there does not exist a price P' such that: (a) $\pi(H, 1, P') > \pi(H)$ and (b) $\pi(L, 1, P') < \pi(L)$. Intuitively, if such a price P' did exist, then uninformed consumers should believe that only a high-quality firm would charge P' , which by (a) causes the equilibrium to fail.⁵

Letting $P(q)$ denote the equilibrium price charged by a type- q firm, we now state our first two lemmas, which are almost obvious.

LEMMA 1: *In any equilibrium, $P(q) \geq P^L$ for $q \in \{H, L\}$.*

PROOF:

The function $\pi(q, b(P), P)$ is strictly increasing in P , for all $q \in \{H, L\}$ and all functions $b(\cdot)$, when $P < P^L$. Thus, were $P(q)$ less than P^L , the type- q firm could increase its price slightly and increase profits.

LEMMA 2: *In any separating equilibrium, $P(H) > P^L$ and $P(L) = P^L$.*

⁵We use the intuitive criterion throughout to restrict the class of equilibria. A weaker refinement is to eliminate dominated strategies (Elon Kohlberg and Jean-Francois Mertens, 1986; Milgrom and Roberts, 1986). This refinement is sufficient for all of our results for separating equilibria and for some of our work on pooling equilibria. The intuitive criterion is necessary, however, for Theorems 3 and 6.

PROOF:

A low-quality firm earns zero profits in a separating equilibrium if $P(L) > P^L$ and positive profits if $P(L) = P^L$. Therefore, the results follows from Lemma 1.

In a separating equilibrium, the low-quality firm charges P^L and the high-quality firm charges some higher price. Moreover, it must be that $\pi(L, 0, P^L) \geq \pi(L, 1, P(H))$; otherwise, the low-quality firm would mimic its high-quality counterpart. We are thus led to consider the set

$$\{P | \pi(L, 0, P^L) = \pi(L, 1, P)\}.$$

This equation has an upper and lower root,

$$\begin{aligned} \bar{P}(X) &= [(1 + P^L)/2] \\ &+ \left(\left[(1 + P^L)^2/4 \right] - P^L(1 + X) \right)^{1/2} \end{aligned}$$

and

$$\begin{aligned} \underline{P}(X) &= [(1 + P^L)/2] \\ &- \left(\left[(1 + P^L)^2/4 \right] - P^L(1 + X) \right)^{1/2} \end{aligned}$$

expressed as functions of X .

We assume that $1 > P^L$ and represent $\bar{P}(X)$ and $\underline{P}(X)$ by the upper and lower boundaries of the parabola in Figure 1.⁶ These equations have no solution for values of $X > \bar{X}$. For $X \leq \bar{X}$, any price inside the parabola, $P \in (\underline{P}(X), \bar{P}(X))$, satisfies $\pi(L, 0, P^L) < \pi(L, 1, P)$; the low-quality firm would mimic any such price. This leads immediately to the following lemma.

⁶If $P^L \geq 1$, then for $\varepsilon = P - P^L > 0$, $\pi(L, 1, P) = \pi(L, 0, P^L) - [P^L X + \varepsilon(P^L - 1) + \varepsilon^2]M/(1 + X) < \pi(L, 0, P^L)$, so that a low-quality firm's marginal revenue for a price increase above P^L is negative no matter how beliefs adjust. Thus, if $P^L \geq 1$, then mimicry is never profitable for the low-quality firm, and the problem degenerates. The following can be shown: if $P^L \geq 1 + c > 1$, then the unique equilibrium has $P(H) = P(L) = P^L$; while if $1 + c \geq P^L \geq 1$, then the unique equilibrium has $P(L) = P^L$ and $P(H) = (1 + P^L + c)/2 \equiv P^H$. $P^L < 1$ is thus the interesting case.

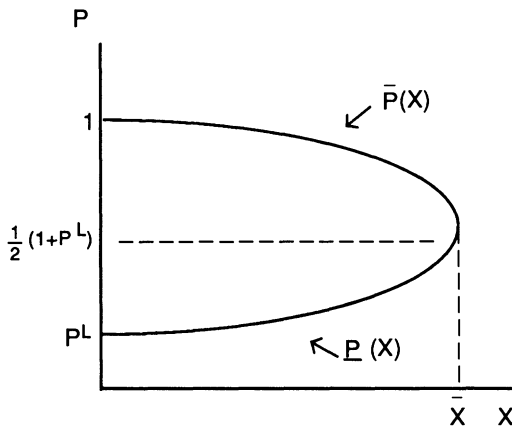


FIGURE 1. SEPARATING PRICES

LEMMA 3: If $X < \bar{X}$, then in any separating equilibrium either $P(H) \geq \bar{P}(X)$ or $P(H) \leq \underline{P}(X)$.

It is important to understand the parabola in Figure 1. By mimicking a high-quality price $P(H) > P^L$, the low-quality firm both gains and loses. It gains by tricking uninformed consumers with reservation prices at or above $P(H)$ into buying at a higher price, but it loses because all informed consumers and the remaining uninformed consumers refuse to buy at that price. The gains outweigh the losses for prices inside the parabola; for these prices, the low-quality firm finds mimicry profitable.

When all consumers are uninformed ($X = 0$), a price slightly above P^L is certainly worth mimicking, as only a very few consumers refuse to buy at the higher price. It follows that the lower branch of the parabola begins at P^L , reflecting the fact that all uninformed consumers buy at this price regardless of beliefs. As price climbs higher, eventually sales to uninformed consumers are sufficiently restricted that mimicry becomes unattractive. The critical price marking the beginning of the upper branch of the parabola is easily shown to be 1. When the ratio of informed to uninformed consumers (X) rises, it becomes increasingly costly for the low-quality firm to mimic its

high-quality counterpart and thereby sacrifice all informed purchases. For this reason, the parabola narrows about $(1 + P^L)/2$, the maximizer of $\pi(L, 1, P)$. This is the low-quality firm's monopoly price when all uninformed consumers believe it to be high-quality. For X above \bar{X} , the low-quality firm refuses to mimic even $(1 + P^L)/2$.

The high-quality firm's full-information monopoly price is $P^H \equiv (1 + P^L + c)/2$, the maximizer of $\pi(H, 1, P)$. However, with uninformed consumers, the high-quality price may be distorted upward as shown in the following theorem. The theorem establishes necessary conditions for a separating equilibrium satisfying the intuitive criterion.

THEOREM 1: $P(H) = \max\{\bar{P}(X), P^H\}$ and $P(L) = P^L$ are the only separating equilibrium prices satisfying the intuitive criterion.

PROOF:

Lemma 2 implies $P(L) = P^L$, so suppose $P(H) \neq \max\{\bar{P}(X), P^H\}$ and consider Figure 2. X^H satisfies $\bar{P}(X^H) = P^H$. For $X > X^H$, the intuitive criterion fails by setting $P' = P^H$. For $X \leq X^H$, Lemma 3 rules out $P(H) \in (P(X), \bar{P}(X))$. Moreover, the intuitive criterion fails for $P' \in (\bar{P}(X), P(H))$ if $P(H) > \bar{P}(X)$, and for $P' \in (P(H), \underline{P}(X))$ if $P(H) < \underline{P}(X)$. This leaves the possibility that $P(H) = \underline{P}(X)$, but it is straightforward to show that $c > 0$ implies $\pi(H, 1, \bar{P}(X)) > \pi(H, 1, \underline{P}(X))$, from which it follows that $P' = \bar{P}(X) + \varepsilon$ violates the intuitive criterion for sufficiently small ε .

Theorem 1 identifies two cases. If $P^H \geq \bar{P}(X)$, then the separating equilibrium has $P(H) = P^H$ and $P(L) = P^L$. This is because the low-quality firm is unwilling to mimic the high-quality firm's favorite price. The more interesting case emerges when $P^H < 1$, or equivalently $P^L + c < 1$, and separation is potentially costly for the high-quality firm. In this case, a supramonopoly price is charged if the ratio of informed to uninformed consumers is small.

COROLLARY 1: If $P^H < 1$ and X is sufficiently small, $P(H) = \bar{P}(X) > P^H$ and $P(L) = P^L$ are the only separating equilibrium prices satisfying the intuitive criterion.

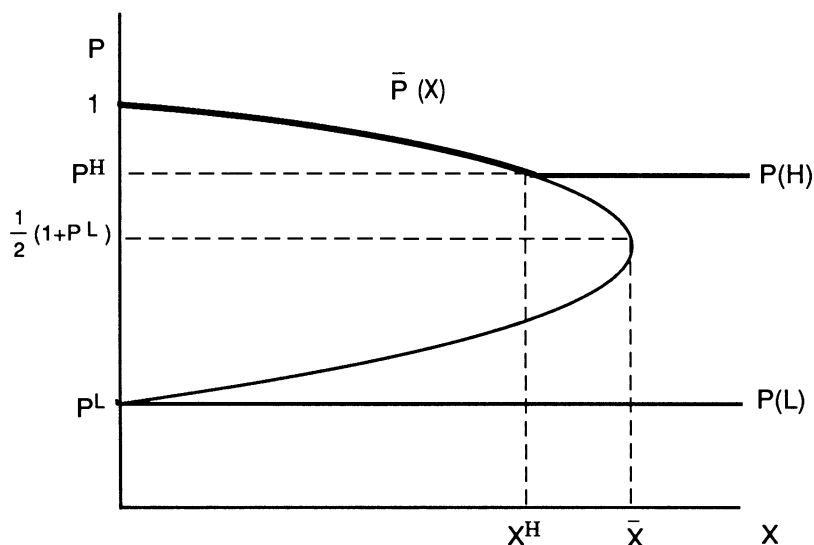


FIGURE 2. EQUILIBRIUM SEPARATING PRICES

For expositional reasons, we assume henceforth that $P^H < 1$.

Figure 2 illustrates the prices charged in a separating equilibrium satisfying the intuitive criterion (the parabola is the same as in Fig. 1). It may seem surprising that a high-quality firm separates with $\bar{P}(X)$ instead of a lower price $\underline{P}(X)$, when X is small. However, a simple intuition underlies this result. Because high-quality production is costly ($c > 0$), the full-information monopoly price P^H is closer to $\bar{P}(X)$ than to $\underline{P}(X)$.⁷ Put differently, the high price is the efficient means of separation because the forgone profit from a lost customer is less for the high-quality firm (Milgrom and Roberts, 1986). Thus, the high-quality firm prefers to separate with the high price.

⁷The assumption that higher-quality firms have at least somewhat higher costs of production is crucial. As the cost asymmetry between qualities diminishes, the high-quality firm's preferred separating price, $\bar{P}(X)$, remains constant; that is, $\bar{P}(X)$ is independent of c . In the limiting case when $c = 0$, prices corresponding to the lower branch of the parabola also satisfy the intuitive criterion. This is because the high-quality firm is then indifferent between $\bar{P}(X)$ and $\underline{P}(X)$. We believe $c > 0$ to be a realistic case.

So far we have characterized necessary conditions for a separating equilibrium. We now turn to existence.

Separation can occur only if the high-quality firm chooses not to monopolize informed consumers at the expense of losing uninformed consumers. Such a deviation is potentially attractive only if separation is costly for the high-quality firm, that is, when $X < X^H$ (see Fig. 2) in which case $P(H) = \bar{P}(X) > P^H$. Prices that might then increase high-quality profit must be inside the parabola and thus must also be prices that could increase low-quality profit. The intuitive criterion does not restrict beliefs for such prices, and at worst a deviation in this range could induce the belief of certain low quality. The high-quality firm will thus charge the price $P(H) = \bar{P}(X)$ when $X < X^H$ in a separating equilibrium if and only if $\pi(H, 1, \bar{P}(X)) \geq \pi(H, 0, P^H)$.⁸ Setting $\pi(H, 1, P) = \pi(H, 0, P^H)$ when $X < X^H$ de-

⁸ P^H is clearly the best price above P^L for the high-quality firm to deviate to when uninformed consumers believe quality is low. The high-quality firm will never deviate from $\bar{P}(X)$ to P^L (or lower), since $\pi(H, 1, \bar{P}(X)) \geq \pi(H, 1, \bar{P}(0)) > \pi(H, 1, \underline{P}(0)) = \pi(H, 1, P^L)$.

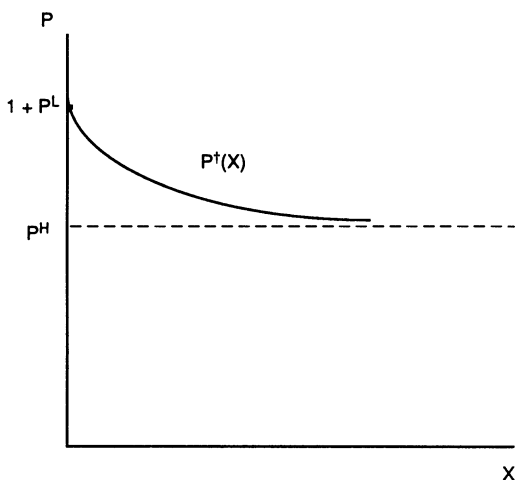


FIGURE 3. NO-DEFECT PRICES

finds a “no-defect” root,

$$P^\dagger(X) = P^H + [(1 + P^L - c)(1 + X)^{-1/2}/2]$$

which begins at $(1 + P^L)$ for $X = 0$ and asymptotically declines to P^H , as shown in Figure 3. The high-quality firm has no incentive to defect if and only if $P(H) \leq P^\dagger(X)$. Since “intuitive” beliefs can entail $b(P') = 0$ for all $P' \in (\underline{P}(X), \bar{P}(X))$, it is easily established that the low-quality firm is also unwilling to defect from the proposed separating equilibrium. We thus have the following existence theorem.

THEOREM 2: *A separating equilibrium satisfying the intuitive criterion exists if and only if $X \geq \bar{X}$ or if $X < \bar{X}$ and*

$$\Delta(X) \equiv P^\dagger(X) - \bar{P}(X) \geq 0.$$

Two observations are in order, which we state below as corollaries. First, a separating equilibrium always exists if the ratio of informed to uninformed consumers is small because $\Delta(0) \equiv P^L > 0$. Second, it can be shown numerically that a separating equilibrium exists for any value of X unless P^L and c are small; Figure 4 illustrates parameter values for which separating equilibria fail to exist for some intermediate X .

COROLLARY 2: *A separating equilibrium satisfying the intuitive criterion exists if X is sufficiently small.*

COROLLARY 3: *A separating equilibrium satisfying the intuitive criterion exists if P^L or c is sufficiently large.*

We next turn to pooling equilibria. The following theorem establishes that, if the percentage of informed consumers is sufficiently small, then the only equilibrium satisfying the intuitive criterion is a separating equilibrium. In other words, when the market is very uninformed, there always exists a high price at which the high-quality firm can profitably distinguish itself.

THEOREM 3: *If X is sufficiently small, then no pooling equilibrium satisfies the intuitive criterion.*

PROOF:

We prove the result for $X = 0$; the result follows for X close to 0 by continuity. Let $Q(P, b) \equiv [1 - (P - P^L)/b]M$ denote the quantity of sales at a price P when consumers believe high quality with probability b . In a pooling equilibrium, $P(H) = P(L) = P^*$, and $b(P^*) = r$. The high- and low-quality firms earn profits $\pi(H) \equiv (P^* - c)Q(P^*, r)$ and $\pi(L) \equiv P^*Q(P^*, r)$, respectively. Clearly $1 + r > P^* \geq \max\{P^L, c\}$; otherwise, one or the other type of firm would defect. Thus, $\pi(L) > \pi(H) \geq 0$. Since $P^*Q(P^*, 1) > \pi(L)$, there exists $P'' > P^*$ such that $\pi(L, 1, P'') \equiv P''Q(P'', 1) = \pi(L)$ and $\pi(H, 1, P'') = \pi(H) + c[Q(P^*, r) - Q(P'', 1)] > \pi(H)$. Moreover, $PQ(P, 1)$ is decreasing in P at P'' . Therefore, $P' \equiv P'' + \varepsilon$ violates the intuitive criterion for $\varepsilon > 0$ sufficiently small.

Pooling is therefore impossible if X is sufficiently small. Similarly, if the market is sufficiently well informed that X is large, then pooling is impossible to maintain, as each firm type prefers to deviate and monopolize informed consumers. For example, if $X \geq \bar{X}$ (see Fig. 1), then pooling is clearly impossible, because the low-quality firm would not select $P > P^L$ even if it were

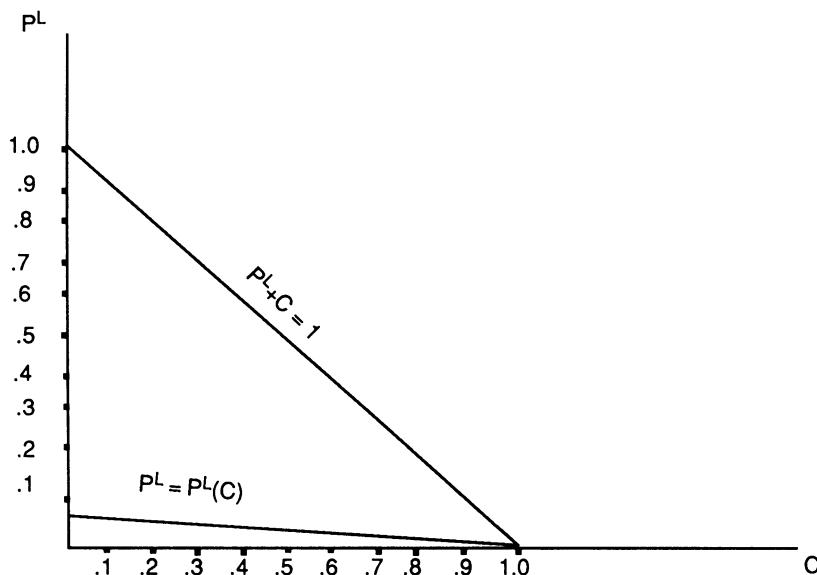


FIGURE 4. PARAMETER VALUES SUPPORTING SEPARATION: FOR $\{P^L, C\}$ SUCH THAT $P^L > P^L(C)$, A UNIQUE SEPARATING EQUILIBRIUM SATISFYING THE INTUITIVE CRITERION EXISTS; IF INSTEAD $P^L < P^L(C)$, A SEPARATING EQUILIBRIUM MAY FAIL TO EXIST FOR INTERMEDIATE VALUES OF X

then believed to certainly have a high-quality product. The critical X beyond which pooling is impossible is actually smaller than \bar{X} , since pooling only generates the belief $b(P(L)) = r$. This point is stated in the following theorem, as is the related point that pooling is impossible when consumers' prior belief of high quality is pessimistic and, correspondingly, the profits from pooling are low.⁹

THEOREM 4: *If $r \leq \max\{P^L, c - P^L\}$ or $X \geq (r - P^L)^2 / 4rP^L$, then no pooling equilibrium exists satisfying the intuitive criterion.*

⁹By Theorems 2, 3, and 4 and Corollary 2, pure-strategy sequential equilibria satisfying the intuitive criterion might not exist if r is small and X is in an intermediate range. However, equilibria do exist satisfying the intuitive criterion in which the high-quality firm selects a price $P(H) > P^L$, the low-quality firm mixes between $P(H)$ and P^L with weights λ and $1 - \lambda$, and uninformed consumers believe high quality with probability b , where $P(H)$, λ , and b satisfy $b = r / [r + (1 - r)\lambda]$, $\pi(H, b, P(H)) = \pi(H, 0, P^H)$, and $\pi(L, b, P(H)) = \pi(L, 0, P^L)$.

PROOF:

By Lemma 1, pooling can never occur at $P < P^L$. Moreover, since $1 > P^L$, pooling at $P = P^L$ violates the intuitive criterion as the high-quality firm would deviate to $\bar{P}(X)$. A necessary condition for pooling at P is $\pi(L, r, P) \geq \pi(L, 0, P^L)$. Suppose pooling occurs at $P > P^L \geq r$. Let $M / (1 + X)$ denote the stock of uninformed consumers and let $\varepsilon \equiv P - P^L > 0$. Then $\pi(L, r, P) = \pi(L, 0, P^L) - [\varepsilon(P^L - r) / r + \varepsilon^2 / r] M / (1 + X) < \pi(L, 0, P^L)$, a contradiction. Suppose next that pooling occurs when $r \leq c - P^L$. Pooling at P requires $P \geq c$ and $P < r + P^L$ (lest the low-quality firm deviate to P^L), which is contradictory. Finally, suppose $r > \max\{P^L, c - P^L\}$. Then it is easy to show that $X \geq (r - P^L)^2 / 4rP^L$ implies that at $P > P^L$, $\pi(L, r, P) \leq \pi(L, r, (r + P^L) / 2) < \pi(L, 0, P^L)$, a contradiction.

Finally, if r is big and X is intermediate, pooling equilibria satisfying the intuitive criterion may exist. The possible prices for such equilibria are easily restricted. First, pooling at or below P^L is inconsistent with the intuitive criterion, as argued in the proof

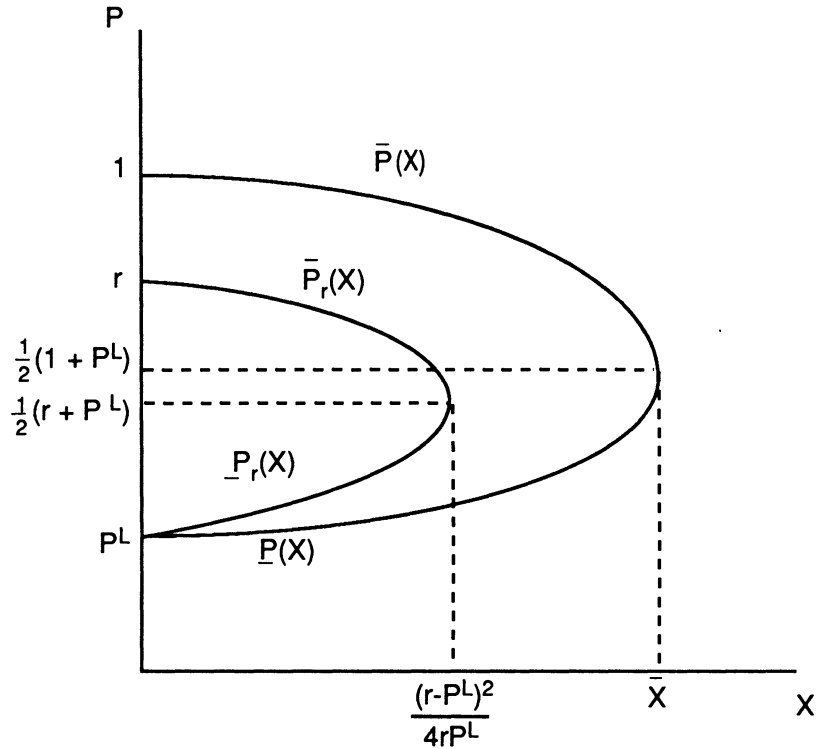


FIGURE 5. THE POOLING PARABOLA

of Theorem 4. Second, given that pooling must occur above P^L , the pooling price must certainly be inside the parabola, or the low-quality firm would deviate to P^L . In fact, since pooling only gives the belief $b(P(L)) = r$, a tighter bound can be found. Setting $\pi(L, r, P) = \pi(L, 0, P^L)$ gives the prices at which the low-quality firm is just willing to pool. The corresponding roots are

$$\begin{aligned} \bar{P}_r(X) &= [(r + P^L)/2] \\ &+ \left(\left[(r + P^L)^2/4 \right] - rP^L(1 + X) \right)^{1/2} \\ \underline{P}_r(X) &= [(r + P^L)/2] \\ &- \left(\left[(r + P^L)^2/4 \right] - rP^L(1 + X) \right)^{1/2} . \end{aligned}$$

As shown in Figure 5, a “pooling parabola” inside the initial (separating) parabola is thus defined. The pooling parabola is drawn under the assumption that $r > P^L$ and is not defined for $X \geq (r - P^L)^2/4rP^L$, as suggested by Theorem 4. Any price outside of the pooling parabola has $\pi(L, r, P) < \pi(L, 0, P^L)$ and therefore cannot be supported as a pooling equilibrium. We thus have the following necessary condition for pooling.

THEOREM 5: *In any pooling equilibrium satisfying the intuitive criterion, $\underline{P}_r(X) \leq P(H) = P(L) \leq \bar{P}_r(X)$.*

Therefore, if an intuitive pooling equilibrium does exist, then r must be large, X must be intermediate, and the pooling price must be lower than the intuitive separating price for high quality.

II. Multiperiod Extensions

A. Interpreting the Static Results

We begin by offering a multiperiod interpretation of the static results of the previous section. Suppose that the market evolves in two periods. In the introductory period, the market is poorly informed about the characteristics of the product; the ratio of informed to uninformed consumers (X_1) is close to zero. Over time, information about the product diffuses through published quality reviews (e.g., *Consumer Reports*). Thus, during the mature phase of the market, the ratio of informed to uninformed consumers (X_2) is larger.

A high-quality product ($q = H$) will be introduced at a price that is distorted above the full-information monopoly price (Corollary 1 and Theorem 3). As information diffuses, it becomes easier to signal high quality, and the size of this distortion is reduced. If X_2 is sufficiently large, then a lower price signals high quality during the mature period (Theorem 4). For intermediate values of X_2 , pooling might occur during the mature phase; however, even a pooling price must be below the introductory price (Theorem 5). Therefore, high-quality products exhibit high and declining prices in either case.

A low-quality product, on the other hand, is introduced and remains at a low price P^L if X_1 is small and X_2 is large (Theorems 1, 3, and 4). If, instead, X_1 is small and X_2 is in an intermediate range, then the product is introduced at a low price but might rise to a higher pooling price in the mature phase (Theorems 1 and 5). However, this possibility is unlikely to be observed, because pooling can occur only if the prior probability of low quality is small (Theorem 4). Therefore, we conclude that, on average, prices will tend to fall as the market evolves.

In summary, our results appear to be consistent with the stylized facts for consumer durables (see the Introduction). Consider a reasonably well-defined product category, such as microwave ovens or color TVs. Over time, quality improvements lead

to the introduction of new products, but information about the value of these improvements diffuses gradually. New, higher-quality products are introduced at higher prices, resulting in a positive rank-order correlation between price and quality. As consumers gain information about new products, prices on average decline over time, since it becomes easier or unnecessary to signal quality, and price differentials narrow.

Finally, a weakened correlation between price and quality might be explained by measurement errors in the data. To understand this point, suppose that price and quality were perfectly rank-order correlated but that price differentials narrowed over time. Suppose further that prices and quality were measured with error and that this measurement error was independently and identically distributed over time. Then the measured rank-order correlation between price and quality would tend to decline.

This interpretation of our static results can be formalized in a two-period extensive-form game under the following assumptions. First, the populations of consumers in each of the two periods are distinct. That is, a consumer enters the market at the beginning of one or the other period, either makes a purchase or does not, and then leaves the market at the end of that period. In other words, we are taking a long-run view of the evolution of the market.

Second, upon entering the market, consumers only observe the current price. Specifically, consumers in the mature phase do not know what price was charged by the firm in the introductory phase. They do, however, know the date, that is, whether they are in the introductory or mature phase. (We relax these assumptions below.) As new consumers are ignorant of past prices, we refer to this model as the *ignorant-consumer model*.

Finally, information diffusion is independent of market activity. During the introductory phase, most consumers cannot distinguish a high-quality product prior to consumption, although some small fraction might be able to do so, say through inspec-

tion, because of some related expertise. During the mature phase, a new population has better information about product quality, because of the availability of published quality reviews. However, the ratio of informed to uninformed consumers in the mature period is independent of the quantity of sales in the first period.

Under these assumptions, the multi-period model decomposes into a sequence of one-period models, with our results of the previous section applying to each period. The fundamental dynamic variable is the ratio of informed to uninformed consumers, X_t , which by assumption increases over time (Bagwell and Riordan, 1986).

The assumption that information diffusion is independent of market activity might be important for our basic conclusion that high and declining prices signal product quality. Suppose instead that the number of informed consumers during the mature phase depends on the number of introductory sales. This might be the case if word-of-mouth communication about personal experience were an important mechanism for information diffusion. In this case, high prices which discourage sales become a less attractive method of signaling high quality. The high-quality firm might instead prefer to signal with a low price, in which case price would tend to rise over time.

However, word-of-mouth communication is not a particularly good method of information diffusion for many products. For example, for many durable products (e.g., smoke alarms), it is difficult to determine quality even after purchase. For such products, quality reviews or the advice of experts are much more important sources of information diffusion.

Further, word-of-mouth communication may be a very noisy source of information if there is an idiosyncratic component to consumer tastes. For example, knowing that my neighbor likes his new microwave oven may not be a very good indicator that I will like it. On the other hand, knowing that 90 percent of consumers like it is much more informative. Published quality reviews, such as those in *Consumer Reports*, accomplish this information aggregation. Our model

could be extended to introduce an idiosyncratic taste component (Milgrom and Roberts, 1986).¹⁰

We conclude that our independence assumption is consistent with a long-run view of markets, in which the primary source of information diffusion is published quality reviews. This seems particularly pertinent for explaining stylized facts based on data published in *Consumer Reports*. It is plausible that the availability of published quality reviews is independent of first-period pricing.

We turn now to a relaxation of some other assumptions about consumer information.

B. Confused Consumers

In the above-described ignorant-consumer model, the ratio of informed to uninformed consumers is common knowledge. In our model, this is equivalent to assuming that each consumer knows the age of the firm, since by assumption X_t increases strictly over time. This is clearly an extreme assumption, as it seems reasonable that consumers might also be incompletely informed about the demand side of the market. We address this issue in a very simple way by assuming that consumers in any period observe only the current price and not the age of the firm. We continue to assume that some fraction of consumers are informed about quality in each period. As consumers are confused about the date, we refer to this model as the *confused-consumer model*.

An important novelty of the confused-consumer model is that the firm now has two dimensions of private information: the

¹⁰The assumption that initial sales volume influences the future information state is in fact problematic, even if quality is nonidiosyncratic and easily evaluated after experience. In particular, in a separating equilibrium, each current consumer believes he knows quality whether or not he chooses to buy. Word-of-mouth communication then affects the rate of diffusion only if a consumer who knows quality communicates more effectively than does a consumer who believes himself to know quality.

quality of its product and the prevailing ratio of informed to uninformed consumers. Consequently, the price set by the firm potentially signals information about both. Uninformed consumers will thus attempt to update their beliefs about both unknown variables.

Formally, we model this situation as a two-period extensive-form game with the following structure. At any period t , the ratio of informed to uninformed consumers is actually X_t . The firm knows this ratio as well as the quality of its product and chooses a price, $P_t(q)$. Uninformed consumers at any date do not observe quality and also do not know whether they are in period one or two. That is, an uninformed consumer knows that $q \in \{H, L\}$ and $X \in \{X_1, X_2\}$, where H , L , X_1 and X_2 are all commonly known values and $X_2 > X_1$, but he does not know the actual realizations of q and X . Upon observing a price P , an uninformed consumer forms a (stationary) belief $b(P)$, representing the likelihood of high quality. In a sequential equilibrium, the belief of uninformed consumers must agree with Bayes' rule for prices that could occur (for some quality and date) in equilibrium.¹¹

The intuitive criterion can be usefully employed in this environment. A sequential equilibrium fails the intuitive criterion if there exists an out-of-equilibrium price P' such that (a) $\pi_t(H, 1, P') > \pi_t(H)$ for some t and (b) $\pi_t(L, 1, P') < \pi_t(L)$ for all t , where $\pi_t(q)$ are equilibrium profits at date t for quality q , with $t \in \{1, 2\}$ and $q \in \{H, L\}$. Intuitively, if there exists an out-of-equilibrium price that is profitable for a high-quality firm at some date when uninformed

consumers believe it to be high-quality, but which is never profitable for a low-quality firm no matter what uninformed consumers believe, then uninformed consumers must believe that there is high quality at that price. In effect, the firm makes an implicit speech as to quality and date with the selection of the price P' .

We will continue to interpret the first period as an introductory phase in which X_1 is close to zero and the second period as a mature phase with X_2 large. Our main result is that the high-quality firm will separate with a high price in period one, and the prices of both types of firm will decline. This equilibrium exhibits intertemporal pooling, in that the young, low-quality firm mimics the price of the mature, high-quality firm.¹² Thus, the general implications of the ignorant-consumer model also are true in the confused-consumer model.

THEOREM 6: *In the confused-consumer model, if X_1 is sufficiently small, then in any equilibrium satisfying the intuitive criterion, $P_1(H) \geq P_2(H)$, $P_1(H) \in (P^H, \bar{P}(X_1)]$, $b(P_1(H)) = 1$, and $P_1(L) \geq P_2(L)$. If in addition X_2 is sufficiently large, then $P_1(H) > P_2(H)$ and $P_1(L) = P_2(H) > P_2(L) = P^L$.*

The theorem has a simple intuition. (A formal proof is in the Appendix.) The declining path of prices follows from the assumption that the number of informed consumers increases through time. As the market becomes more informed, distortions away from complete-information monopoly prices become more costly. Thus, a rising price profile is not an optimal strategy for a firm, since it entails greater distortions when the market is more informed. The firm would be better off, for example, to reverse the order of its two prices. The assumption that the number of informed consumers is initially small is not important in ruling out rising price profiles but does ensure that the introductory high-quality price separates; the logic is similar to that for Theorem 3.

¹¹The specific nature of the consumer arrival process will determine the consumers' priors over dates. It is perhaps easiest to imagine that the process treats consumers anonymously, pulling out a certain fraction in period one and the remainder in period two, in which case consumers have common priors over dates (Bagwell and Riordan, 1986). The consumers' priors over dates will affect beliefs as to quality only for prices that would be charged at different dates by the high- and low-quality firms. In any event, Theorem 6 below characterizes the necessary characteristics of equilibrium and is independent of the details of the arrival process.

¹²Bagwell and Riordan (1986) give an example of an equilibrium with these characteristics.

It is interesting to note that the initial high-quality price in the confused-consumer model is never higher and, indeed, may be lower than the corresponding price in the ignorant-consumer model when X_1 is small. Since the introductory period is when the low-quality firm has the greatest incentive to mimic, the price $\bar{P}(X_1)$ is sufficient to separate even when consumers are confused as to the date. Furthermore, an introductory price strictly below $\bar{P}(X_1)$ may separate when consumers are confused, because the low-quality firm initially earns a larger profit by mimicking the mature, high-quality price than by charging P^L .

C. Hindsightful Consumers

We close this section by briefly considering another assumption, that consumers observe both the age of the firm and the entire history of prices; we call this model the *hindsightful-consumer model*. This is a strong assumption (e.g., past prices are not typically reported in *Consumer Reports*).

In this model, uninformed consumers in period one observe a first-period price P_1 and attempt to infer quality, while uninformed consumers in period two base their beliefs on a pair of prices, P_1 and P_2 . Sequential equilibrium then requires that the beliefs of an uninformed consumer be consistent with Bayes' rule for any price or pair of prices that could occur in equilibrium. The sequential equilibria of the ignorant-consumer model are also equilibria of this model but have the property that consumers always ignore past prices in forming beliefs about product quality. However, there also exist other equilibria in which period-two consumers base their quality beliefs at least partially on period-one price.

Cho (1987) has generalized the intuitive criterion to multiperiod settings such as this. However, as Cho (1987 p. 1385) notes, this refinement is often very weak, and this is true in our model as well.¹³ Nevertheless,

¹³The problem is that almost any deviant first-period price could improve profits for the low-quality firm, if the deviation were favorably interpreted by period-two

there do exist plausible sequential equilibria—other than those of the ignorant consumer model—that are consistent with the stylized conclusion that high and declining prices signal quality.¹⁴

A particularly focal equilibrium is that which is the Pareto dominant separating equilibrium for the firm. To find this equilibrium, we solve

$$\max_{\{P_1, P_2\}} [\pi_1(H, 1, P_1) + \delta\pi_2(H, 1, P_2)]$$

subject to

$$\pi_1(L, 1, P_1) \leq \pi_1(L, 0, P^L)$$

and

$$\pi_1(L, 1, P_1) + \delta\pi_1(L, 1, P_2)$$

$$\leq \pi_1(L, 0, P^L) + \delta\pi_2(L, 0, P^L)$$

where δ is a common discount factor. Our fundamental result is that the Pareto dominant separating equilibrium is characterized by high and declining high-quality prices, while low-quality prices are constant at P^L . The price dynamics for the hindsightful-consumer model are again qualitatively the same as for the ignorant-consumer model. In each case, the high-quality price begins high and then declines as the number of informed consumers increases and signaling becomes easier.

THEOREM 7: *In the hindsightful-consumer model, the Pareto dominant separating equilibrium is characterized by $P_1(H) \geq \bar{P}(X_1)$, $P_2(H) = P^H$ if $X_2 \geq X^H$, $P_2(H) \in [\bar{P}^H, \bar{P}(X_2)]$ if $X_2 < X^H$, and $P_1(L) = P_2(L) = P^L$.*

consumers. It follows that, using the intuitive criterion, period-one consumers are generally unable to associate a deviation with the high-quality product.

¹⁴For a more thorough discussion of the types of plausible separating equilibria in the hindsightful-consumer model, see Bagwell and Riordan (1989).

The proof of Theorem 7 is straightforward (Bagwell and Riordan, 1989).

It is interesting to compare the Pareto dominant separating equilibrium for the hindsighted-consumer model with the separating path in the ignorant-consumer model. Numerical calculations reveal that the two paths agree if P^L is large. However, if P^L is small and X_2 is not too large, the hindsighted-consumer model's equilibrium has $P_1(H) > \bar{P}(X_1)$ and $P_2(H) < \bar{P}(X_2)$. Here, the high-quality firm "front loads" the signaling process by signaling strongly in the introductory phase and then profit-taking in the mature phase.¹⁵

A general theme seems to arise from a comparison of the ignorant-, confused-, and hindsighted-consumer models. In the focal separating equilibria of these models, the initial high-quality price is at least as high in the hindsighted- as in the ignorant-consumer model, and is at least as high in the ignorant- as in the confused-consumer model. In effect, the more information consumers have about the initial period, the more difficult and the more important it is for the high-quality firm to signal strongly in that period. Since signaling involves high prices, the initial high-quality price is highest when consumers have hindsight and lowest when they are confused.

III. Conclusions

A high-quality good will be introduced at a high price that is lowered over time toward the full-information monopoly price. The high introductory price signals high quality, because a high-cost firm is more

willing to restrict sales volume than is a low-cost firm. Furthermore, a low-quality firm loses greater sales volume from a high price, since informed consumers refuse to buy at such a price. As information about product quality diffuses and more consumers become more informed, it therefore becomes easier for a high-quality firm to signal its quality. High-quality prices thus decline as the market matures.

Our prediction of high and declining prices is consistent with the stylized facts of the marketing literature.¹⁶ In particular, our model provides an explanation for the declining trends in consumer durables of real prices, price differentials between competing brands, and the rank-order correlation between price and quality.

The prediction is robust to a variety of assumptions about consumer information. Whether or not uninformed consumers know past prices and firm age, intuitively plausible equilibria exist in which high-quality products have high and declining prices.

Our model relies on many special features that can be relaxed. For example, linear demands and costs are not crucial for our conclusions.¹⁷ The two-period framework is also easily extended into a many-period setting.

Many interesting extensions do remain. It would be worthwhile to study an explicit model of word-of-mouth communication. Further empirical work might investigate how price-quality relationships depend on the amount and type of consumer information. One intriguing possibility is to interpret the publication of a *Consumer Reports* evaluation of a product group as a proxy for an increase in the "fraction of informed consumers." This suggests the empirical test that a *Consumer Reports* publication should itself lower the relative price of high-quality items and weaken price-quality correlation.

¹⁵More generally, since the ignorant-consumer equilibrium is not always the hindsighted-consumer equilibrium, the high-quality firm has a clear incentive to ensure that past price information is available to uninformed consumers. By equipping consumers with hindsight, the high-quality firm may be able to generate a more profitable equilibrium. This point is reminiscent of work by B. Douglas Bernheim and Michael D. Whinston (1990), who argue that firms may seek multi-market contact so as to pool incentive constraints. Analogously, we find that a high-quality firm may want consumers to observe its past pricing decisions so as to pool its "no-mimic" constraints through time.

¹⁶It should be noted, however, that at least some of our "stylized facts" are in fact controversial (Valarie A. Zeithaml, 1988).

¹⁷Bagwell (1990) establishes that high prices signal a high-quality product in a model that allows for a general demand function and product quality choice.

APPENDIX

PROOF OF THEOREM 6:

Observe first that $P_t(H) > P^L$ and $P_t(L) \geq P^L$. $P_t(q) < P^L$ is impossible in equilibrium, as $P_t(q) = P^L$ earns greater profit always. Also, $P_t(H) = P^L$ is inconsistent with the intuitive criterion, because $\pi_t(H, 1, \bar{P}(X_1)) - \pi_t(H, b(P^L), P^L) > 0$ and $\pi_t(L, 1, \bar{P}(X_1)) \leq \pi_t(L, b(P^L), P^L) \leq \pi_t(L)$.

Next, X_1 small implies $b(P_1(H)) = 1$. To see this, suppose $b(P_1(H)) < 1$. From the proof of Theorem 3, there exists $P'' > P_1(H)$ such that $\pi_t(L, 1, P'') = \pi_t(L, b(P_1(H)), P_1(H)) \leq \pi_t(L)$ and $\pi_t(H) = \pi_t(H, b(P_1(H)), P_1(H)) < \pi_t(H, 1, P'')$. $P' = P'' + \varepsilon$ with $\varepsilon > 0$ and small, then violates the intuitive criterion.

Given $b(P_1(H)) = 1$, $P_1(H) \in (P^H, \bar{P}(X_1)]$ follows. To see this, note that $P_1(H) = P^H$ induces $P_2(H) = P^H$ and thus $P_1(L) = P^H$, which contradicts $b(P_1(H)) = 1$. Further, $P_1(H) < P^H$ violates the intuitive criterion; for if $P_1(H) \in [(1 + P^L)/2, P^H)$, then $P' = P_1(H) + \varepsilon$, for $\varepsilon > 0$ and small, violates the intuitive criterion. On the other hand, if $P_1(H) < (1 + P^L)/2$, then as in the proof of Theorem 1, $P'' > P^H$ can be found for which $\pi_t(L, 1, P'') = \pi_t(L, 1, P_1(H)) \leq \pi_t(L)$ and $\pi_t(H, 1, P'') > \pi_t(H, 1, P_1(H)) = \pi_t(H)$. $P' = P'' + \varepsilon$ then violates the intuitive criterion. Finally, $P_1(H) > \bar{P}(X_1)$ is also inconsistent with the intuitive criterion, as can be seen by setting $P' = P_1(H) - \varepsilon$.

$P_1(H) \geq P_2(H)$ is straightforward to establish. Otherwise, since $b(P_1(H)) = 1$ and $P_1(H) > P^H$, $\pi_2(H) = \pi_2(H, b(P_2(H)), P_2(H)) < \pi_2(H, 1, P_1(H))$, and so the high-quality firm would do better to select $P_1(H)$ in period two as well.

Consider next $P_t(L)$. Clearly, $P_t(L) = P^L$ or $P_t(L) = P_2(H)$ at any t . $P_1(L) = P^L$ and $P_2(L) = P_2(H)$ is impossible, since

$$\begin{aligned} & \pi_2(L, b(P_2(H)), P_2(H)) \\ & \geq \pi_2(L, b(P^L), P^L) \end{aligned}$$

implies $\pi_1(L, b(P_2(H)), P_2(H)) > \pi_1(L, 0, P^L)$, contradicting $P_1(L) = P^L$. Hence, $P_1(L) \geq P_2(L) \geq P^L$.

We now impose the additional assumption that X_2 is sufficiently large, taken here to mean $X_2 > \bar{X}$ and $P^+(X_2) < \bar{P}(X_1)$. $X_2 > \bar{X}$ implies $P_2(L) = P^L$, while $P^+(X_2) < \bar{P}(X_1)$ can be shown to imply $P_2(H) \in (P(X_1), \bar{P}(X_1))$. The latter result gives $P_1(L) = P_2(H)$. Since $b(P_1(H)) = 1$ and $P_2(H) > P^L$, we thus have $P_1(H) > P_2(H) = P_1(L) > P_2(L) = P^L$.

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