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Price and Quality in a New Product Monopoly

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In a signal-extraction model of consumer behaviour, higher prices signal higher-quality products for a new product monopoly, even without cost asymmetries across different qualities. Moreover, higher-quality products earn greater expected profits, and the monopolist has an incentive to provide even transient improvements in quality. Finally, the monopolist has a positive incentive to conduct market research about quality, and produces more information than is socially optimal.

1. INTRODUCTION

The phrase "you get what you pay for" is a commonplace saying for the idea that a high price signals high quality. The problem with this folk wisdom is well-known; why doesn't each firm, independent of its true quality level, charge a high price in order to get consumers to infer high quality? Consideration of this puzzle leads to a number of related questions. How much do consumers need to know about a firm's technology in order to understand the information contained in a firm's price? Does a firm have an incentive to produce a high-quality product or to gather information about the quality of its product? Is there a role for regulation to force a firm to learn more about its product? This paper introduces a signal extraction model of consumer behaviour and learning that addresses these and other questions in an integrated fashion.

Recent work on price as a signal of quality in product markets (Milgrom and Roberts (1986), Ramey (1986), Bagwell and Riordan (1991)) has shown that a truly high-quality firm may be more willing than an imitator to charge a high price because of its higher cost. Consequently, a price sufficiently above the full information monopoly level can signal high quality in equilibrium if the cost differences among qualities are sufficiently large. This approach has limited appeal because it relies on a perfect correlation between cost and quality. Such a perfect correlation does not perfectly capture the notion of quality if by "quality" we mean the utility a product provides to the consumer. The assumption of perfect correlation between quality and cost is appropriate if we mean to model, for example, the close fit between the doors and body of an automobile or the reliability of an air conditioner. However, a more general notion of quality would also include the final utility that the consumer enjoys. For example, penicillin treatment for a bacterial disease is cheaper than treatment by a voodoo doctor, but we believe the former to be of greater quality. The focus on aspects of quality that are perfectly correlated with costs also yields some unintuitive results. For example, that approach can imply that higher-quality products have smaller equilibrium price-cost margins, so that any incentive to invest in quality relies on repeat purchases (Ramey (1986)).

We explore an alternative approach to price and quality determination in a new product monopoly, based on a signal-extraction model of consumer behaviour. In order to highlight the distinctions between our approach and earlier work, we assume that costs and quality are uncorrelated. A key feature of our model is that the firm and consumers both possess valuable private information about the individual-specific utility of the product. We find that because consumers have some (possibly small amount of) information about a product's quality that the monopolist does not possess, the monopolist is able to signal its private information through price even in the absence of cost asymmetries or repeat purchases. Furthermore, higher quality products have higher margins and earn greater proifits even in the short run, thus providing the firm an incentive to invest in quality.

The crucial dynamic aspect of our model is active equilibrium learning by consumers. More specifically, we decompose individual utility into a population-average willingness to pay and an individual-specific willingness to pay. Consequently, a consumer's belief about the value of the product to him depends both on his own direct experience and on an inference he draws from the price. A monopolist with information that the value to consumers is likely high can signal that information through a high price because he knows that the average consumer already has some corroborating information. Thus, a consumer infers a high average valuation from a high price, but his own information about quality dampens the inference he draws from price about the value of the product to himself. Part of the reason that a firm with only an average quality product does not want to falsely signal a higher quality is that an average consumer, while believing the price signal, will conclude from his own experience that his individual valuation is nevertheless low, and thus still choose to buy only a relatively small amount. Essentially, a consumer's private information limits the extent to which the monopolist can deceive him, a condition that makes the monopolist somewhat trustworthy.

We extend our signalling model to examine the provision of quality, and offer a substantially less pessimistic view of quality choice by firms than does some previous literature. We show that firms may invest in improved quality in equilibrium even when such investment improves only current quality. This arises because of persistence effects generated by the signal extraction aspect of consumer inferences. More specifically, if the firm's period-one investment in quality exceeds the level expected by consumers, then the average consumer enjoys a greater than expected utility from period-one consumption, causing him to overestimate the basic quality level of the product and leading to an increased period-two demand. This marginal incentive to provide transient quality will be strongest when consumers have the least information concerning true product quality, that is, when the product is new. Hence, as consumers learn more about their own preferences, product quality can be expected to decay with age.

Finally, we address some regulatory issues related to the informative content of product markets. Regulators representing consumer interests care about the extent to which producers test their products before they market them. Another extension of our model examines the determination of how much information the producer acquires before and during sales and the impact of possible regulations. Since the monopolist is uncertain about consumer demand, it has some incentive to gather the information in order to set a more profitable price. We show that a monopolist prefers the public to learn the extent to which it tests a new product, but that this leads to less product testing in equilibrium.

Moreover, even with observable testing, too much testing is provided from a social standpoint. Thus there is no case for regulation requiring product testing.

In order to make the examination of these issues tractable, we take a linear-quadratic approach uncommon in the industrial organization literature, but common in the finance literature (for example, Admati and Pfleiderer (1986), Hellwig (1980), Kyle (1989)) and the macroeconomics literature on rational expectations equilibria (for example, Cukierman and Meltzer (1986)). While the approach is similar, it is not identical to that taken in those literatures.

We propose this model as a simple one in which we can begin to examine several important questions concerning the informational content of prices and the performance of markets with imperfect information about product quality. We hope to demonstrate that a quality-signalling framework is potentially quite rich. Section 2 describes the general model, special cases of which are examined in turn. Section 3 develops a simple case of our model wherein prices signal quality. Section 4 studies a model with endogenous quality provision, and Section 5 studies a case with endogenous information acquisition. Section 6 concludes.

2. THE GENERAL MODEL

Our model is based on a simple specification of tastes and technology. First, the value to individual i in period t ($t=1, 2$) is represented by an index, y_{it}, which is equal to

$$y_{it}=x+\eta_i+v_{it}+u_t.$$

We assume that if individual i knew y_{it}, he would demand $q_{it}=y_{it}-p_t$ units of the good in period t if price were p_t. This implies that consumer i would be willing to pay $y_{it}q_{it}-q_{it}^2/2$ for q_{it} units in period t. However, since he does not know y_{it} at the time of purchase, consumer i demands $E\{y_{it}-p_t|\Omega_{it}\}$, where Ω_{it} is consumer i's information at time t.

This representation of the quality index corresponds to an intuitive decomposition. The random variables x, η_i, and v_{it} represent the population-average marginal willingness-to-pay, individual i's persistent deviation from that population average, and his specific time-t deviation. u_t represents the firm's improvement in period t quality, which costs the firm $\beta u_t^2/2$. In keeping with those interpretations,

$$E\{\eta_i\}=E\{v_{it}\}=0.$$

Furthermore, define

$$E\{x\}=\bar{x}.$$

The variances of x, η, and v are σ_x^2, σ_η^2, and σ_v^2. It will become clear that the monopolist has no incentive to invest in quality in period two; hence $u_2=0$ and we focus on the determination of u_1.

Before proceeding, we give some interpretations of this taste specification. The variable x represents how well, on average, consumers like the new product, i.e., it is the expected willingness to pay by consumers. It can be interpreted to depend on product features as well as population characteristics, but it is not directly observable.

The η_i terms represent persistent differences among consumers. This could represent different utility functions (e.g., only some consumers like "the new taste of Coke"), or could represent persistent aspects of the local and household production (e.g., iced tea is preferred in warm climates). We do not make any assumptions concerning the covariance structure of the η_i shocks.

The ν_{it} terms represent idiosyncratic, serially uncorrelated "shocks" to preferences (e.g., mood swings). Alternatively, these shocks might represent shocks to the household production function (e.g., unknown to anyone else, a child left the refrigerator door open, causing some spoilage), or shocks to local aspects of production (e.g., there were some difficulties at the local distributor's warehouse).

Finally, u_t represents period-specific and commonly experienced improvements in product performance. However, the value of u_t is not directly observable. It might be interpreted as an input of managerial supervision; e.g., restaurant food will taste better the more closely its preparation is supervised by a knowledgeable chef. It could also represent an unobservable material input; e.g., products made with higher quality steel are sturdier.

The notion of quality being represented here is purely one of private value. We do not necessarily assume that there is some objective standard for quality. This view of quality as being "just a matter of taste" is more general than often analysed, in particularly allowing for the possibility that quality can be independent of cost. Quality in this model is just a measure of what consumers like.

The equations above decompose private valuations into some average desirability, some individual-specific deviations, and some time-specific deviations. We will, however, assume that x, η_i, and ν_{it} are all normally and independently distributed. Normality has the unpleasant feature of an unbounded support, allowing the possibilities of negative demand and price. If $\bar{x}$ is large and variances small then these events occur with small probability, and the normality assumption can be interpreted as an approximation of a more realistic specification. On the other hand, normality has the highly desirable feature of implying linear updating rules for consumers, which simplifies our analysis considerably. We believe that the principal intuitive results that emerge are quite general.[1]

The firm's private information about product quality is represented by a signal, z, which gives information about x:

$$z = x + \psi$$

where $E(\psi) = 0$, i.e., z is unbiased estimator of x. ψ is assumed to be normal with variance σ^2_ψ, and independent of all the other random variables specified above. We generally assume that the firm observes z only after first-period sales. This can be interpreted to mean that the firm undertakes some market research following initial sales, to determine how well the product has performed or to what extent consumers like the product. This timing assumption on the firm's private information simplifies the exposition in places. However, we can also assume that the monopolist observes this information before period-one sales; for example, by laboratory product testing that reveals certain attributes of the product. It turns out that such first-period information is neither valuable to the firm nor in equilibrium can be signalled until after consumers have acquired some corroborating information of their own. Therefore, private information of the firm only matters in period

1. Our linear-quadratic-Gaussian model does have a rigorous interpretation. One could think of the cases of negative demand as situations where the "consumer" really produces the product, his cost function represented by this "demand" function, and the "producer" really consumes the product, such consumption having a marginal utility equal to what we call the marginal cost. Therefore, negative production is consumption with a marginal cost function equal to $q - y_{it}$, and the firm in such situations is a monopsonist. This interpretation gives a rigorous specified structure in which we can examine questions of information transmission through price-setting since the firm always sets the price.

two, and we can adopt either a market research or a product testing interpretation for z.

With the definition of z we can now give a more complete interpretation of x and the η_i. Given the lack of assumptions on the covariance structure of the η_i random variables, x is really that portion of the mean effect on the population which is detectable through z. If the η_i are independent, then z signals the actual average population experience with the product. If the η_i are correlated, then x is not the average experience ex post, just the ex ante expectation. However, z remains an unbiased predictor of the average experience of the population. In this case, the monopolist can be interpreted as learning about one component of average experience, but not another, e.g., market research might identify consumer preferences along one dimension of the product but not another, or product testing might concern only one aspect of performance.

We first take γ_z to be exogenous, but in Section 5 allow that the firm and/or society can choose γ_z to be γ at a cost of $c(\gamma)$. We want to investigate cases where the information represented by z comes from a variable activity, such as laboratory testing or market research. Endogenizing γ_z allows us to ask whether a firm or industry will supply the "right" amount of information to the market.

We assume that unit production cost in each period is common knowledge and normalized to zero. To complete the description of our general model, we next discuss the order in which actions are taken and information revealed. First, in period zero, γ_z is determined by either society or the firm (or by nature) and may or may not be directly observed by consumers; we examine various cases. This is an expositional convenience; we could allow γ_z to be determined after period-one sales which might be more natural for some market research or product testing interpretations.

The market for the product opens in period one. The monopolist chooses a first-period quality investment, u_1, and announces first-period price. Consumer i observes the price, makes his purchase, consumes the good, and observes his individual experience, y_{i1}.

At the beginning of period two, the firm learns z, the signal about average product quality, x. It then chooses second-period price. Each consumer, recalling their individual experience in period one (but knowing no other consumer's experience), sees that price, possibly drawing an inference about the firm's observations of z, and chooses second period purchases.

We do not solve the general model below. Instead, we first examine the case in which γ_z is fixed by nature and common knowledge among all consumers and the firm, and where first-period quality investment is not done because, say, β is prohibitively high. This basic case concentrates on the possibility of quality signalling by price in period two. The basic case is then extended to examine in isolation the possibilities of endogenous determination of first period quality investment, and the supply of information when γ_z is endogenous.

3. EQUILIBRIUM FOR THE BASIC CASE

We first examine the case where γ_z is fixed and known, and there is no quality augmentation in period one (implicitly assuming $\beta=\infty$.) Given these specifications, certain conditional expectations should be noted for future reference. Since all random variables are normal, the following conditional expectations are just regression equations:

$$E\{y_{i1}|z\}=\gamma_z z+\gamma_x \bar{x}$$

with

$$\gamma_z \equiv \sigma_x^2/\sigma_z^2 \quad \text{and} \quad \gamma_x \equiv 1-\gamma_z;$$

and

$$E\{y_{i2}|y_{i1}, z\} = \alpha_y y_{i1} + \alpha_z z + \alpha_x \bar{x}$$

with

$$\begin{aligned}\alpha_y &\equiv (\sigma_x^2\sigma_\psi^2 + \sigma_\eta^2\sigma_z^2)/(\sigma_y^2\sigma_z^2 - \sigma_x^4)\\ &= [(1-\gamma_z)\sigma_x^2 + \sigma_\eta^2]/[(1-\gamma_z)\sigma_x^2 + \sigma_\eta^2 + \sigma_v^2],\\ \alpha_z &\equiv \sigma_x^2\sigma_v^2/(\sigma_y^2\sigma_z^2 - \sigma_x^4),\\ &= \gamma_z\sigma_v^2/[(1-\gamma_z)\sigma_x^2 + \sigma_\eta^2 + \sigma_v^2],\end{aligned}$$

and

$$\alpha_x \equiv 1 - \alpha_y - \alpha_z.$$

In these formulas $\sigma_y^2 \equiv \sigma_x^2 + \sigma_\eta^2 + \sigma_v^2$ and $\sigma_z^2 \equiv \sigma_x^2 + \sigma_\psi^2$. Two useful identities are:

$$\begin{aligned}\alpha_z &\equiv \gamma_z(1-\alpha_y)\\ \alpha_x &\equiv (1-\gamma_z)(1-\alpha_y).\end{aligned}$$

Given these identities, the two key parameters of our model are α_y and γ_z. The former indicates how much weight consumers place on their own experience in drawing an inference about quality. The latter indicates the precision of the monopolist's private information.

Before proceeding with the formal analysis, let us reason intuitively about the nature of equilibrium second-period pricing. At the beginning of period two both consumers and the firm have information. Each consumer remembers his first-period experience, which yielded an observation of y_{i1}, and the firm has observed z. A high z indicates a high x, which in turn indicates that each consumer's observation, y_{i1}, is likely to be high. Thus the firm concludes from a high z that second-period demand is likely to be high, which supports a high expected profit maximizing price. Consumers understand these incentives for the firm, and so naturally infer something about the firm's observation of z from the price. Information about z is useful to the consumer since it provides an independent signal of the true value of x, a component of his utility function. However, since some of his utility experience with the good is idiosyncratic, he will continue to use his personal information, y_{i1}, in making quality inferences. We conclude below that equlibrium does in fact possess these features; however, the presence of idiosyncratic signals to the consumers is crucial.

We examine the unique differentiable separating equilibrium, ignoring pooling equilibria. In this equilibrium, the firm's second-period price is a linear function of its private information. The linear solution is intuitive. If consumers use ordinary least squares to compute mean expectations about z, (say, calling on their past experience with new products,) they will be using linear rules necessarily. Linear inference rules by the consumer in turn make linear decision rules by the firm optimal. Rational expectations (or Bayes–Nash) equilibrium is often justified by some story of how agents will learn over time the true structure of the economy. When one uses the convergence scheme studied by Marcet and Sargent (1989) in their work on convergence, one finds that our linear equilibrium is stable. We ignore pooling possibilities since our objective is to show that prices may signal quality and to investigate the implications of this for related questions. Nonlinear partial pooling equilibria, if they exist, will most likely display similar qualitative features.

The first step in computing the Bayes–Nash, or equivalently, rational expectations, equilibrium is to specify exactly what consumer i believes at any possible information set. Each consumer's information set at the beginning of period two consists of his own observation of y_{i1} plus the commonly observed p_2 which possibly indicates the firm's observation of z. Suppose consumers make inferences on z from p_2 according to the linear rule $z = a + bp_2$. Period two demand by consumer i conditional on his information is then given by

$$\begin{aligned} q^d_{i2} &= E\{y_{i2}|y_{i1}, p_2\} - p_2 = E\{E\{y_{i2}|y_{i1}, z\}|y_{i1}, p_2\} - p_2 \\ &= E\{\alpha_y y_{i1} + \alpha_z z + \alpha_x \bar{x}|y_{i1}, p_2\} - p_2 \\ &= \alpha_y y_{i1} + \alpha_z(a + bp_2) + \alpha_x \bar{x} - p_2. \end{aligned}$$

The demand curve perceived by the firm is the expectation of the representative consumer's demand conditional on his own information and the second-period price. The firm also observes first-period sales of course, but this information is not valuable because it does not indicate any private information of the consumers, i.e. consumers only have common knowledge information when they make first-period purchases. It follows that the firm's second-period expected demand equals

$$\begin{aligned} E\{q^d_{i2}|z, p_2\} &= \alpha_y \gamma_z z + \alpha_z(a + bp_2) + \gamma_x \bar{x} - p_2 \\ &\equiv A - Bp_2. \end{aligned}$$

Notice that an increase in price has two distinct effects on demand. First, there is the direct effect of reducing demand for a given level of perceived quality reflected in the -1 component of the coefficient of p_2. However, there is a second effect of price reflected in the $\alpha_z\, b\, p_2$ term. This reflects the fact that a dp_2 increase in price will cause the consumer to make a $d_z b\, dp_2$ greater inference about the expected level for y_{i2} leading to an increase in demand of the same amount. If $\alpha_z\, b$ is large, that is, if each consumer places large weight on z in estimating his y_{i2}, and therefore places a large weight on p_2 in drawing inferences about z, then the demand curve becomes steeply sloped and the monopoly price is high; if $\alpha_z b > 1$ no finite monopoly price exists.

We search for a solution wherein $1 - \alpha_z b$ is positive, implying that the monopolist's second-period pricing problem is well-defined. The important point to note is that when b is positive (as it will be in equilibrium) an increase in price will not depress demand by as much as it would in the absence of signalling, leading to a price which exceeds the complete information monopoly price. Thus, the fact that consumers draw inferences about quality from price steepens the monopolist's demand curve, i.e. makes demand less elastic at any particular quantity.

Given the expected demand curve faced by the firm, its optimal period-two price is

$$\begin{aligned} p_2 &= A/2B \\ &= \tfrac{1}{2}[\gamma_x \bar{x} + \alpha_z a + \alpha_y \gamma_z z]/(1 - \alpha_z b). \end{aligned}$$

Note that this period-two price is indeed a linear function of z. We are searching for an equilibrium in which the representative consumer's inference rule is correct, that is, if the firm charges p_2 then consumers are correct in believing that the z observed by the firm actually equals $a + bp_2$; then p_2 must also satisfy $p_2 = (z - a)/b$. Hence, in a linear separating equilibrium:

$$b = 1/[\gamma_z(1-\tfrac{1}{2}\alpha_y)]$$

$$a = -\gamma_x\bar{x}/\gamma_z.$$

Substituting this solution into the firm's pricing equation, the equilibrium pricing rule becomes

$$p_2 = (1-\tfrac{1}{2}\alpha_y)[\gamma_z z + \gamma_x\bar{x}].$$

Note that $\gamma_z z + \gamma_x\bar{x} > 0$ and $0 < \alpha_y < 1$ imply

$$p_2 > \tfrac{1}{2}[\gamma_z z + \gamma_x\bar{x}].$$

This means that the equilibrium second-period price exceeds the monopoly price with z common knowledge (and sufficiently large that the quantity sold is positive). Moreover, setting $z = \bar{x}$, the expected period-two price necessarily exceeds the expected complete information monopoly price, i.e., signalling distorts price upwards on average.

A limiting case of some interest is when α_y goes to zero; this occurs if σ_v^2 becomes infinite or if γ_z goes to one and σ_η^2 goes to zero. Price will be nearly z, the average period-two willingness to pay, and expected period-two demand is zero. This limiting case corresponds to the firm's private information, z, being a sufficient statistic for consumers' estimates of product quality, either because consumers' observations of y_{i1} is uninformative about y_{i2} or because z perfectly signals x to the firm and the persistent idiosyncratic component of tastes, η_i is certain. In this case the problematic nature of the folk wisdom of our introduction is apparent; if price were a sufficient statistic for inferring quality, then not only could all types of firms convince consumers of a higher quality with a higher price, but all would have exactly the same incentive to do so. The only way the monopolist can convincingly signal quality to consumers is to produce nothing. Thus, absent any asymmetry of costs for different qualities, a necessary condition for price to profitably signal quality is that the monopolist's private information not be a sufficient statistic for consumers. Some idiosyncratic information learned by consumers is crucial.

On the other hand, as consumers' private information becomes a sufficient statistic for product quality, i.e., σ_v^2 goes to zero, then the price converges to the full information monopoly price. In this limiting case the firm has nothing to signal, since its information is valueless to consumers. For intermediate cases, we find the usual result that the more important price is as a signal of quality, e.g. the larger is γ_z, the greater the distortion of price above the full information monopoly level.

Note that expected period-two profits equal

$$\Pi_2 = A^2/4\beta$$

$$= \frac{\alpha_y}{2}\left(1-\frac{\alpha_y}{2}\right)(\gamma_z z + \gamma_x\bar{x})^2.$$

and is monotonically increasing in z. Thus higher quality products tend to be more profitable since quality is positively correlated with z. This would give the firm an incentive to make ex ante investments in quality, which shifts the distribution of x to the right, contrary to signalling models relying on cost asymmetry (Ramey (1986)).

The first-period price decision is trivial. Since neither the firm nor the consumers have any information, the first-period price is just the monopoly price corresponding to the unconditional average quality level. Thus, we have found a complete solution to the equilibrium pricing problem.

Theorem I. *If γ_z is fixed and common knowledge, and $\beta=\infty$, then*

$$p_2=\left(1-\frac{\alpha_y}{2}\right)[\gamma_z z+\gamma_x\bar{x}]$$

and

$$p_1=\bar{x}/2$$

Furthermore, this is the unique equilibrium where consumers' inferences about z are a differentiable and invertible function of p_2.

Proof. The calculations above showed that this is a linear equilibrium. The uniqueness property follows from the nature of the signalling differential equation. Assume that consumers infer $z=\hat{z}(p)$ if second-period price is p, where $\hat{z}$ is C^1. The demand curve faced by the firm in period two is

$$\alpha_y\gamma_z z+\gamma_x\hat{z}(p)+\gamma_x\bar{x}-p.$$

The profit-maximizing price satisfies the first-order condition

$$\alpha_y\gamma_z z+\alpha_z\hat{z}(p)+\gamma_x\bar{x}-2p+\alpha_z p\hat{z}'(p)=0$$

and implicitly defines the correct inference rule, $z(p)$. In a Bayes–Nash equilibrium, consumers use the correct inference rule, that is, $\hat{z}(p)=z(p)$; hence, $z(p)$ must solve the ordinary differential equation

$$(\alpha_z+\alpha_y\gamma_z)z(p)+\alpha_z pz'(p)=2p-\gamma_x\bar{x}.$$

After dividing through by $\alpha_z p$, this differential equation can be written as $z'(p)+rp^{-1}z(p)=s+tp^{-1}$ where $r=(\alpha_z+\alpha_y\gamma_z)/\alpha_z$, $s=2/\alpha_z$, and $t=-\gamma_x\bar{x}/\alpha_x$. Pre-multiplying this differential equation by p^r yields

$$\frac{d}{dp}(p^r z(p))=p^r(z'(p)+rp^{-1}z(p))$$

$$=p^r(s+tp^{-1})$$

which, after integration, implies that

$$p^r z(p)=p^{r+1}s(r+1)^{-1}+p^r tr^{-1}+C$$

for some constant C. If $z(0)$ is finite, as must be the case in a separating equilibrium, then $C=0$. Hence $z(p)$ is linear in p. ‖

We have adopted a two-period interpretation of our model, with first-period consumption giving individuals information about their own valuation of the good. While it may appear that the repeat purchase nature of that story is important to our second-period analysis, this is not the case. All that is important about the first period is the information is provides, information which could have arisen from other mechanisms, such as inspection or informative advertising. While a full multi-period extension of our model would be unduly complicated, some of the comparative static results implicit in Theorem I are nevertheless suggestive. For example, as consumers learn more about the idiosyncratic component of their tastes, price should decline over time, becoming closer to its full information level (cf. Bagwell and Riordan (1991)).

It is also clear that the linear-quadratic structure of the problem is not critical to the analysis. While a more general nonlinear signalling analysis is possible, we chose to use a structure with a closed-form solution to the price-signalling aspect of the problem. This makes it possible to embed a period-two price signalling analysis into richer models which incorporate other interesting elements, allowing us to examine below the implications of the period-two signalling effects on other aspects of conduct and performance. It should also be apparent that the intuitive underpinnings of our result do not depend on normality.[2]

One of the strong features of this equilibrium is that an arbitrarily small amount of individual-specific information known by each consumer will allow for a fully-separating equilibrium. One interesting question is whether the distribution of information affects the nature of equilibrium. We next examine a version of our model with heterogeneous consumer information sets to show that full revelation can occur in period two even if only an arbitrarily small number of consumers have an arbitrarily small amount of information.

Suppose only a fraction θ of the consumers received a signal about product quality in period one because, say, others were unaware of or unable to purchase the product in the first period. Then, if they draw the inference $z=a+bp_2$, the demand function for consumer i is

$$q^d_{i2}=\begin{cases}\alpha_y y_{i1}+\alpha_z(a+bp_2)+\gamma_x\bar{x}-p_2, \text{ if informed,}\\ \gamma_z(a+bp_2)+\gamma_x\bar{x}-p_2, \text{ if uninformed.}\end{cases}$$

The firm's perceived demand function is

$$\begin{aligned} q^d_2 &= \gamma_x\bar{x}+\theta(\alpha_y\gamma_z z+\alpha_z(a+bp_2))+(1-\theta)\gamma_z(a+bp_2)-p_2 \\ &= \gamma_x\bar{x}+\theta(\alpha_y\gamma_z z+a\alpha_z)+(1-\theta)\gamma_z a+(\theta b\alpha_z+(1-\theta)\gamma_z b-1)p_2 \end{aligned}$$

implying a monopoly price equal to

$$p_2=\frac{\gamma_x\bar{x}+\theta\alpha_y\gamma_z z+\theta a\alpha_z+(1-\theta)a\gamma_z}{2(1-b(\theta\alpha_z+(1-\theta)\gamma_z))}.$$

In equilibrium, $p_2=(z-a)/b$, implying

$$b=[(1-\theta)+\theta(1-\alpha_y/2)]^{-1}\gamma_z^{-1}.$$

Straightforward calculations also yield a unique solution for a.

This generalization shows that, in a certain sense, it is the aggregate amount of idiosyncratic information that affects the nature of equilibrium, not its distribution. The generalization also indicates the standard externality from the informed to the uninformed arising from the firm's inability to detect which customers are informed.

This section has examined a basic case demonstrating that price can signal quality even if production cost is independent of quality. The critical novel assumption is that the firm's private information is not a sufficient statistic for product quality for some consumers. We now explore the implications of price signalling for some other industrial organization questions.

2. An important simplifying feature of our model is that consumers know the slope of their demand curves. If the unknown quality term determined the slope of a consumer's demand instead of its intercept, then consumers would learn more by purchasing more, and first period purchases would reflect a learning-by-doing motive (Grossman, Kihlstrom, and Mirman, (1977)). This would complicate our analysis.

4. ENDOGENOUS QUALITY

An important question in the economics of imperfect information is: why do firms make investments in improving their product when such improvements cannot be observed by the consumer until after he has purchased the product? Some models rely strongly on an infinite sequence of purchases (Klein and Leffler (1981), Shapiro (1983)). Others rely on persistence and observability of quality improvements (Shapiro (1982), Wolinsky (1983), Farrell (1986), Riordan (1986), Ramey (1986)). In this section we extend our analysis to show that a firm may have an incentive to produce high-quality products when there are only two periods and quality improvements are transient and unobservable.

In this section, we assume that the firm may invest in quality in the first period, with such investment improving quality only for the period. More specifically, we assume that

$$y_{i1} = x + \eta_i + v_{i1} + u_1$$

where u_1 is the augmentation of quality by the firm in period one. The cost of that investment is $\beta u_1^2/2$, $\beta > 0$. In this section, we continue to assume that γ_z is fixed and common knowledge.

The new step in our analysis is to adjust the period-two expectations formulas to reflect the customers' belief about period one quality investment, u_1^e. They become

$$E\{y_{i1}|z\} = \gamma_z z + \gamma_x \bar{x} + u_1^e$$

and

$$E\{y_{i2}|y_{i1}, z\} = \alpha_y(y_{i1} - u_1^e) + \alpha_z z + \alpha_x \bar{x}.$$

We again compute a linear equilibrium. If consumers believe that $z = a + bp_2$, then proceeding as before

$$\begin{aligned} q_{i2}^d &= E\{\alpha_y(y_{i1} - u_1^e) + \alpha_z z + \alpha_x \bar{x} | y_{i1}, p_2\} - p_2 \\ &= \alpha_y(y_{i1} - u_1^e) + \alpha_z(a + bp_2) + \alpha_x \bar{x} - p_2 \end{aligned}$$

and

$$\begin{aligned} E\{q_{i2}^d|z, p_2) &= \alpha_y(\gamma_z z + \gamma_x \bar{x}) - \alpha_y(u_1^e - u_1) + \alpha_z(a + bp_2) + \alpha_x \bar{x} - p_2 \\ &\equiv \bar{A} - Bp_2 \end{aligned}$$

The monopolist's profit-maximizing period-two price is

$$\begin{aligned} p_2 &= \bar{A}/2B \\ &= [(\alpha_x + \alpha_y \gamma_x)\bar{x} + \alpha_z a + \alpha_y(\gamma_z z - (u_1^e - u_1))]/(2 - 2\alpha_z b) \end{aligned}$$

which must equal $(z - a)/b$ in a rational expectations equilibrium. Hence

$$b = 2/(2\alpha_x + \gamma_z \alpha_y) \equiv 1/(\gamma_x(1 - \tfrac{1}{2}\alpha_y))$$

as before, and

$$a = -[\gamma_x \bar{x} + \alpha_y(u_1^e - u_1)]/\gamma_z.$$

Note that $a = -(\gamma_x/\gamma_z)\bar{x}$ if expectations are correct.

The monopolist chooses u_1 to maximize total profit. Note that while the monopolist incurs the cost for this investment in period one, the expected benefit accrues to the firm only in period two through the positive effect of the investment on consumers' beliefs about quality. This period two effect is

$$\frac{\partial \Pi_2}{\partial u_1} = 2\frac{\partial \bar{A}}{\partial u_1}\bar{A}/4B = \alpha_y \bar{A}/2B$$

while the period one marginal cost is βu_1. Hence, taking expectations over z, the first-order condition for u_1 is

$$0 = \alpha_y[(1-\alpha_z)\bar{x} + \alpha_z a - \alpha_y(u_1^e - u_1)]/2B - \beta u_1 .$$

In equilibrium consumers' expectations are correct, hence $u_1^e = u_1$ and [3]

$$u_1 = \alpha_y(2-\alpha_y)\bar{x}/2\beta.$$

The firm's second-order condition requires that $\beta > \alpha_y(2-\alpha_y)/2$; β must be sufficiently large so that profit is bounded. Under this condition, we conclude that $0 < u_1 < \bar{x}$. The profit-maximizing p_1 is the full information price corresponding to the expected quality, $\bar{x} + u_1$. This completes the solution to the monopolist's problem.

Theorem II. *If γ_z is fixed and $\beta > \alpha_y(2-\alpha_y)/2$, then*

$$u_1 = \alpha_y(2-\alpha_y)\bar{x}/2\beta$$

$$p_1 = \tfrac{1}{2}(\bar{x} + u_1),$$

and p_2 is as in Theorem I.

The interesting feature in this solution is that even though quality investment does not affect second-period utility directly, the firm still makes the investment since marginal first-period quality investment will affect each consumer's inference about his individual-specific valuation and his second-period demand. The result depends on quality signalling in period two only to the extent that the precision of the firm's private signal influences how much weight consumers place on their own experience. Even if the firm had no private information about quality ($\gamma_z = 0$), the firm would still have an incentive to temporarily improve quality. Indeed, the better is the firm's private information, i.e. the higher is γ_z, the less is the incentive. In this sense, quality improvements and signalling distortions are inversely related.

Note that both the firm and consumers benefit from the first-period quality improvements, which arise only because consumers are learning. However, quality falls over time since second-period quality investment is zero. We conjecture that this quality degradation result holds more generally in a multi-period model in which consumers learn about their tastes over time gradually.

This explanation for endogenous investment in product quality is quite different from what has appeared in the product quality literature before. Repeat purchases and "reputation" do matter, but differently than in previous literature where the investment is a

3. Making this substitution, the first-order condition solves to

$$u_1 = \frac{\alpha_y[(1-\alpha_z)\bar{x} + \alpha_z a]}{2\beta B}$$

Using the equilibrium value for a and identities $\alpha_z \equiv \gamma_z(1-\alpha_y)$ and $\gamma_z \equiv 1-\gamma_x$, the numerator simplifies to $\alpha_y^2\bar{x}$. Using $B = 1 - \alpha_z b$ and the equilibrium value for b, the denominator simplifies to $\alpha_y/(2-\alpha_y)$. Cancellation yields the final expression for u_1.

response to an implicit bonding arrangement. The explanation also differs from models where quality improvements are permanent. In our model, the monopolist invests in quality only to manipulate consumers' beliefs about quality, and, therefore, future demand. This argument is related to the "signal-jamming" models of oligopoly interaction (Riordan (1985), Fudenberg and Tirole (1986)) or managerial incentives (Holmstron (1982)).

5. ENDOGENOUS INFORMATION PRECISION

The sections above assume that the precision of the firm's information, indexed by γ_z, is fixed. However, in many situations the firm can affect the precision of its information. For example, one interpretation of our z signal is that it represents "testing" of the product, either laboratory testing of the good or market research about consumer desires prior to sales. The extent of such testing is chosen by the firm, and determines the precision of firm's information. Our approach to information acquisition differs substantially from other recent literature that focusses on how consumer skepticism affects incentives for firms to voluntarily acquire and disclose test results (e.g. Farrell (1986), Matthews and Postlewaite (1985)). In our model, information precision matters because it affects the price distortions induced by signalling.

In this section, we allow the firm to chose the precision of its information, i.e., γ_z is endogenous. More precisely, we hold σ_x^2 constant and assume the firm determines γ_z by an implicit choice of σ_ψ^2. We determine the equilibrium level of γ_z under various specifications of the informational and regulatory environment. In order to concentrate on the determination of γ_z, we assume that there is no period-one quality investment. For expositional clarity, we assume that γ_z is chosen at some initial time prior to the introduction of any specific good.

The cost of achieving precision γ_z is $c(\gamma_z)$. We assume that $c(\cdot)$ is increasing and convex, $c(1)=c'(1)=\infty$ and $c(0)=c'(0)=0$. Since $\gamma_z=1$ corresponds to the firm having perfect information about x, it is natural to assume that the total and marginal cost of eliminating the last bit of uncertainty is infinite. Since $\gamma_z=0$ corresponds to no information, it is reasonable to assume that the marginal cost of the first bit of information is zero. These assumptions yield interior solutions for the firm's choice of γ_z.

First, we assume that γ_z is chosen by the firm, but is not directly observable by the consumers. The consumers form some point expectation of γ_z, the value of which determines their point beliefs about the regression coefficients α_y and α_z, which generate their predictions about product quality from z and their information. We denote consumers' (common) belief about the firm's quality of information by γ_z^e. This translates into an equilibrium belief about the values of α_y and α_z, which we denote by α_y^e, and α_z^e. These beliefs in turn determine the period-two coefficients, a and b, of the consumers' period-two inference rule, $z=(a-p_2)/b$.

For given consumer beliefs about γ_z and the resulting inference parameters, we can compute each consumer's period-two demand function as in Section 3, replacing the true values of α_y and α_z with believed values, α_y^e and α_z^e. However, the firm's expectation of y_{i1} conditional on z depends on the true γ_z. Solving for the profit-maximizing price and substituting into the profit function, period-two expected profit conditional on z equals[4]

$$v=\tfrac{1}{4}[(1-\alpha_z^e-\gamma_z\alpha_y^e)\bar{x}+\alpha_z^e a+\gamma_z\alpha_y^e z]^2/(1-\alpha_z^e b).$$

4. This follows from $v=\max_p pE\{q_{i2}^d|z\}$, with $E\{q_{i2}^d|z\}=\alpha_y^e E\{y_{i1}|z\}+\alpha_z^e(a+bp_1)+\alpha_x^e\bar{x}-p_2$, and $E\{y_{i1}|z\}=\gamma_z z+(1-\gamma_z)\bar{x}$.

Hence the firm chooses γ_z to maximize $E\{v\} - c(\gamma_z)$, where the expectation is taken over z (since γ_z is chosen ex ante.) Note that profits on period one sales are unaffected by the γ_z choice, and again we assume no discounting.

The first-order condition for the firm's problem is

$$\frac{\gamma_z(\alpha_y^e)^2\sigma_z^2}{2(1-\alpha_z^e b)} = c'(\gamma_z)$$

and the second-order condition is easily seen to be satisfied. In a Bayes-Nash equilibrium, consumers' beliefs are correct:

$$\gamma_z^u = \gamma_z^e,\ \alpha_y = \alpha_y^e,\ \alpha_z = \alpha_z^e$$

where γ_z^u denotes the equilibrium value of γ_z when the firm's choice of γ_z is unobservable. Imposing the Bayes–Nash equilibrium conditions, substituting for b, and simplifying yields the equilibrium condition

$$c'(\gamma_z^u) = \alpha_y\left(1 - \frac{\alpha_y}{2}\right)\sigma_x^2 \equiv K(\gamma_z^u)$$

where $K(\gamma_z)$ is the marginal profit of information precision. Since

$$d\alpha_y/d\gamma_z = -(1-\alpha_y)^2\sigma_x^2/\sigma_v^2 < 0$$

we conclude that

$$K'(\gamma_z) = \sigma_x^2(1-\alpha_y)d\alpha_y/d\gamma_z < 0.$$

It is easily shown that $K(0) > 0$ if $\sigma_\eta^2 > 0$. Therefore, our assumptions on $c(\cdot)$ assure a unique interior value for γ_z^u. All of the results derived in the basic model apply to this model with γ_z determined endogenously. In particular, the second period price exceeds the complete information level.

Next, we examine the case where the firm can choose γ_z and credibly communicate its value to the consumers. This could arise, for example, if γ_z were determined by durable and irreversible investment which became known to consumers, or if there were some reputation or certification mechanism. In this case, the firm chooses γ_z to maximize expected profits taking into account its impact on consumer inferences in the second period.

Given that consumers observe γ_z, the corresponding ex ante second-period expected profit can be found by setting $\alpha_z^e = \alpha_z$, $\alpha_y^e = \alpha_y$ in the previous expression for v and simplifying, yielding

$$V = \frac{\alpha_y}{2}\left(1 - \frac{\alpha_y}{2}\right)E\{[(1-\gamma_z)\bar{x} - \gamma_z z]^2\}.$$

The first-order condition for maximization with respect to γ_z becomes

$$c'(\gamma_z) = K(\gamma_z) + \left(\frac{1-\alpha_y}{2}\right)(\gamma_z\sigma_x^2 + \bar{x}^2)\frac{d\alpha_y}{d\gamma_z}$$
$$< K(\gamma_2)$$

since $d\alpha_y/d\gamma_z < 0$.

It follows that γ_z^o, the firm's choice for γ_z when its choice is observable, is less than γ_z^u. The intuition for this is clear. If the consumers' belief of γ_z decreases, then the same price signals a higher quality in the second-period equilibrium, leading to greater sales. The reason for this is that consumers put more weight on their own experience (i.e., α_y rises) and less on the firm's information (α_z falls). Thus it becomes easier for a truly high-quality firm to separate itself through price signalling, i.e., price distortions decrease. By committing to a lower value of γ_z, the monopolist can reduce unprofitable price distortions in period two.

We next evaluate the socially optimal choice of γ_z, assuming this choice is revealed to consumers before they make their purchases. The *constrained* social optimum, γ_z^*, is interpreted here to mean the maximization of expected social surplus subject to the constraint that the product is sold by a monopolist. Since we take the monopolistic market structure as given, we rule out policies such as having a government agency collect the information, freely disseminate it, and rely on free entry and competition to push prices down to marginal cost. The question we examine is whether social surplus could be increased by increasing or decreasing γ_z relative to the level chosen by the monopolist.

Expected social surplus in period two equals expected producers surplus, v, plus expected consumer surplus, CS. To derive CS, it is convenient to construct two random variables:

$$Z \equiv \gamma_z z + \gamma_x \bar{x}$$

is the firm's prediction of y_1 given z, and

$$Y \equiv y_{i1} - Z$$

is the error in that prediction. From the definitions, it follows that

$$E\{Z^2\} = \bar{x}^2 + \gamma_z \sigma_x^2$$

and

$$E\{Y^2\} = \sigma_y^2 - \gamma_z \sigma_x^2.$$

From the pricing formula and the utility function, the expected consumer surplus in period two, expressed as a function of α_y and γ_z, equals

$$\begin{aligned} CS(\alpha_y, \gamma_z) &= \frac{\alpha_y^2}{2} E\{Y^2\} + \frac{\alpha_y^2}{8} E\{Z^2\} \\ &= \frac{\alpha_y^2}{2}(\sigma_y^2 - \gamma_z \sigma_x^2) + \frac{\alpha_y^2}{4}(\bar{x}^2 + \gamma_z \sigma_x^2) \end{aligned}$$

To address the social surplus question we need only examine how an increase in γ_z affects expected consumer surplus since the monopolist sets γ_z so that its marginal impact on expected producer's surplus is zero. γ_z affects CS directly in the expression above, but also indirectly through its affect on α_y. It is useful for expositional reasons to distinguish these two types of effects.

As consumers rely more on their own idiosyncratic information, i.e., α_y increases, the equilibrium pricing distortions are less and consumer surplus increases. This is reflected in $CS_{\alpha_y} > 0$. Holding other parameters fixed, a higher value of γ_z necessarily reduces α_y:

$$\frac{d\alpha_y}{d\gamma_z} = -\frac{\sigma_x^2}{\sigma_v^2}(1-\alpha_y)^2 < 0.$$

Therefore, $(d\alpha_y/d\gamma_z)\ CS_{\alpha_y} < 0$, so the indirect effect of γ_z on CS through α_y is always negative.

The direct effects of γ_z on CS are intuitive. Notice that, for fixed a_y, consumers would like both $E\{Y^2\}$ and $E\{Z^2\}$ to be large. If $E\{Z^2\}$ is large, then either the expected value of the good, $\bar{x}$, is large, or the firm's prediction of x is accurate, making the information content of z more useful to consumers. If $E\{Y^2\}$ is large, then the firm's estimate of y_1 is poor and consumers benefit from the firm's resulting inability to extract monopoly rents. Notice further that an increase in γ_z increases $E\{Z^2\}$ but decreases $E\{Y^2\}$. This indicates a tradeoff between consumers learning more from z and the firm learning more about y_1. However, it can be seen from the expression for CS that the coefficient on $\gamma_z\sigma_x^2$ in $E\{Y^2\}$ dominates, hence the net direct effect of an increase in γ_z on CS is negative. Therefore, the direct and indirect effects of γ_z are mutually reinforcing, and consumers are made unambiguously worse off by a better informed firm. In choosing the precision of its information, the firm ignores this negative externality, and so overinvests in information.

Theorem III. *If $\beta=\infty$, $c'(1)=\infty$, $c'(0)=0$, and c is convex and increasing, (i) then the firm buys more information when consumers cannot observe the quality of this information than when consumers see the information quality, and (ii) and the firm always buys too much information relative to the social optimum, i.e.,*

$$\gamma_z^* < \gamma_z^o < \gamma_z^u.$$

We find a rather strong result in a somewhat surprising direction, that is, firms learn too much about their products. In general, this model gives no support for forcing firms to learn more about their products before selling them. It is interesting that the disclosure literature has ambiguous policy implications for regulation of product testing, but for different reasons (Matthews and Postlewaite (1985)), and the ambiguities there are not resolved by focussing on reasonable situations.

Care must be taken in interpreting these results. Our analysis deals with a particular type of information which affects pricing decisions in a particular fashion. Other analyses which focus on other types of information may reach different conclusions. The interesting aspect of our analysis is that these questions can be addressed in a non-trivial way.

7. CONCLUSION

Our model is capable of exploring many issues in the economics of product quality. We have found that price can play a signalling role as long as consumers have some amount of their own information, not in the hands of the firm, about product quality. However, firms distort their pricing decisions in an effort to manipulate consumer beliefs about product quality. Moreover, also as a result of consumers learning from their experiences, firms have an incentive to temporarily enhance the quality of new goods to make consumers think the product is better than it is. Finally, there is no general case for a regulatory policy that would force firms to find out more about their products.

We believe that there are many questions that can be fruitfully studied in this simple model. We have only touched on the most basic exercises and there are many other potentially interesting extensions. One extension we have explored in detail is to relax the assumption that production cost is common knowledge, supposing instead that the firm privately knows its true cost (Judd and Riordan (1989)). In this case we find that asymmetry of information about both cost and quality can lead to a double-signalling outcome. The first-period price will be distorted downward and signal cost, whereas the second-period price will be distorted upward and signal quality. Without second-period signalling about quality, there would be no first-period signalling about cost. This example possibly illustrates a general lesson: an asymmetry of information along one dimension may make asymmetries along other dimensions important.

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