New and Improved?*

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Abstract

Are new versions of products necessarily better? We analyze product innovation by a firm that engages in research and development designed to improve an existing product, the outcome of which is uncertain. If the firm adopts the innovation its modified product appears to consumers as "new and improved," but consumers do not immediately know whether or how much the product is better. We find that new products are on average improved and therefore command a pricing premium. This induces some types to exploit the innovation signal by selling new versions that are only trivially different from their older version or that require inefficiently high upgrade costs. Nevertheless, the incentive to "show off" by introducing a new product may improve total welfare by inducing more innovation adoption and thereby mitigating the standard monopoly underinvestment problem. Firms benefit ex-ante from better consumer information about quality or from committing to not exploit their informational advantage.

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1 Introduction

How do consumers update their beliefs about a "new" or "improved" version of a product before purchase? For example, should a student buy the latest edition of a college textbook or get a used copy of an older edition? Would a consumer who is told "roads change by as much as 15% every year" be more likely to purchase a GPS device with an updated map? Or suppose a familiar household cleanser's packaging states "WOW! Powerful New Formula," but its price has increased by 10%. Is the touted improvement in performance worth the higher price?

In each of these examples consumers are likely unaware of the exact value offered by the "new" or "improved" version of the product. Facing perhaps thousands of such new products each year, consumers must discern major breakthroughs from the more common incremental improvements before making their purchase decision. For their part, although firms may devote significant resources to research and development the outcome of such efforts is highly volatile and often results in failure (Stevens and Burley, 1997). Firms must decide which research outcomes to implement and which to censor from the market, knowing that some consumers may not be willing or able to become immediately informed of the new product's value.

This paper uses a signaling model to investigate the incentive of firms to introduce improved products and the welfare consequences of these introductions when consumers are uncertain of the quality of the improvement. Consumers form beliefs about quality knowing the product exceeds the firm's minimal threshold for new product launch. We find this leads to a "newness premium" resulting from the information conveyed in equilibrium by the very existence of the new product version. This premium in turn incentivizes more upgraded products to be released and so has implications for profits and welfare.[1]

[1]Note this information-based account differs from the marketing literature which has generally explained consumer attraction to new products by a desire for uniqueness, stimulation, or novelty-seeking (Roehrich, 2004; Hirschman, 1980).

We present a model in which a monopolist decides whether to adopt an innovation, the quality of which is the result of a stochastic research and development (R&D) process. The firm knows the true value of the innovation while consumers initially only observe the binary "innovation signal" of whether or not the product has been modified. Consumers form beliefs about product value and buy (or not) accordingly, and then learn from product trial and other sources such as product review websites so that they are more informed in the second period when they repeat their purchase decision. We find that consumers correctly expect the average quality of modified products to be higher, but because of this expectation, firms whose R&D has generated only a trivial improvement or even a harmful "improvement" have an incentive to present the product as new and improved. The result is a partial pooling equilibrium in which consumers are initially unsure whether modified products represent a genuine improvement. In making a trivial improvement firms face a trade-off between inducing an initial "new product" premium and the loss of future profits when the true quality is revealed.

That the firm might incur upgrade costs to sell a new product version that is only trivially different from the old may appear to unambiguously lower welfare. Indeed, we find there are parameter values such that the equilibrium strength of the new product signal is large relative to the firm's upgrade costs, which leads to socially inefficient upgrades. However, a stronger incentive to signal may result in a net gain to welfare by offsetting previously existing distortions. It is well known that under full information a monopolist has less marginal incentive to make costly upgrades than does the social planner due to the firm's inability to appropriate all of the benefits of the innovation (Arrow, 1959). In the present context, a firm may reject a product innovation whose upgrade expense is justified by the increase in welfare but not profits. By providing an additional incentive to make a product upgrade, the innovation signal alleviates Arrow's underinvestment problem and so may increase welfare.

Although welfare may or may not rise, we show the equilibrium effect of consumers' initial lack of information is to unambiguously lower expected profits. This arises from the fact that significantly improved versions are not fully rewarded by consumers wary of the trivially new products firms may occasionally introduce. By the same logic we find that the more difficult it becomes for consumers to learn about product quality from experience the lower the expected profits.

Relation to prior literature

We model a situation close to that of Milgrom and Roberts (1986), who themselves formalized ideas proposed by Nelson (1970, 1974). In their model, a monopolist has private information about its exogenously determined product quality and must choose price and dissipative advertising expenditures that induce beliefs among consumers who are uninformed in the first period but informed thereafter. As Milgrom and Roberts describe it, theirs is a model "...in which the firm's R&D effort has generated a product of some particular given quality that the firm must decide how to introduce." We instead consider the information content of the antecedent decision of *whether* such a product should be introduced at all.

The Milgrom and Roberts result has many variants and extensions applied to monopoly (Kihlstrom and Riordan, 1984; Wilson, 1985; Horstmann and MacDonald, 1994; Daughety and Reinganum, 1995), duopoly (Fluet and Garella, 2002; Yehezkel, 2008) and oligopoly (Janssen and Roy, 2010). Price signaling can even occur in a one-period model when some proportion of consumers is informed about product quality (Bagwell and Riordan, 1991; Linnemer, 2002), while models of "umbrella branding" have shown that extending a brand name from an existing to an unknown new product can be a signal of quality (Wernerfelt, 1988; Cabral, 2000; Miklós-Thal, 2012). The common thread among each of these models is a firm choosing marketing variables such as price, advertising, or brand name to signal its exogenous quality. We abstract from these already well-understood mechanisms to focus on a new one: the product adoption decision itself. Because every "new and improved" product is the output of a random R&D process that has survived the firm's censoring rule, the existence of the new product version may serve as a signal of improved quality.

To a limited extent then, our firm has some control over its product's quality. However, the model differs from the endogenous quality literature that focuses on the moral hazard problem of the firm (see Spence, 1977, Wolinsky, 1983, and Miklós-Thal and Schumacher, 2013; among others). In that literature stream, it is assumed the firm derives a cost benefit from supplying a low-quality product while purporting it is of high-quality. Consequently, a firm with both high quality and cost may suffer from consumer wariness of being cheated and thus a corresponding low willingness to pay.[2] The present model differs from such models in two main respects. First, the unobservable component of the firm's quality "choice" is limited to accepting or rejecting a random R&D outcome, not a deterministic choice as in endogenous quality models. Second, there are no difference in production costs between types, a crucial component of endogenous quality models.

We focus on innovation signaling as a particular way to transmit private information from sellers to buyers, though other mechanisms exist. Crawford and Sobel (1982) showed that coarse information can be conveyed even when firms can costlessly make claims whose truth is unverifiable to consumers. The ensuing cheap talk literature contains numerous extensions of this result, including the ability of such communication to induce more consumer search (Mayzlin and Shin, 2011; Gardete, 2013) or make comparative claims about a product (Chakraborty and Harbaugh,

[2]Various mechanisms have been proposed to ameliorate this problem, including reputation or offering a brand name as collateral (Spence, 1977; Klein and Leffler, 1981; Allen, 1984; Choi, 1998), price signaling (Wolinsky, 1983) as well as risk-sharing devices such as warranties (Grossman, 1981) and money-back guarantees (Mann and Wissink, 1988). Biglaiser (1993) models middlemen as quality guarantors while Miklós-Thal and Schumacher (2013) examine the role of third-party monitors.

2014). The driving force of our model differs from these because it is the existence of the new product version that serves as the firm's message, and product launch and upgrade expenses imply this message is costly to send.

In our model adoption of an innovation is a form of partial disclosure. Our paper is therefore related to the disclosure literature following Lizzeri (1999) in which an intermediary certifies the seller's type, or in other related models, the seller directly discloses to consumers.[3] In either case the disclosing party has commitment power and chooses a disclosure policy that is ex-ante optimal, and it is generally found that high types reveal themselves while lower types are pooled together. In contrast, in our model the firm lacks commitment power and so the threshold disclosing type must be ex-post incentive compatible. There is also an interesting parallel to the classic disclosure literature, beginning with Milgrom (1981). In that literature the lowest disclosing type has incentive to separate from those pooled below him, while in our paper the lowest disclosing type has incentive to pool with those "new and improved" types above him.

The finding that "new" versions may differ only trivially from the old relates to prior work in which the firm degrades or otherwise denies the consumer the full value of its product. For example, Deneckere and McAfee (1996) showed that firms can price discriminate by "crimping" a product—that is, degrading its performance and selling both the high and low quality versions. Oligopolists may engage in "planned obsolescence" whereby they produce goods with uneconomically short useful lives, forcing customers to make otherwise unnecessary repeat purchases (Bulow, 1986). And Moorman et al. (2012) found evidence some firms withhold innovative new products from the market for strategic reasons.

While we show the private benefit from signaling quality can induce more new product launches and raise welfare, other examples of seemingly excessive signaling

[3]See, for example, Gill and Sgroi (2012), Guo and Zhao (2009), and Rayo and Segal (2010).

actions increasing welfare can be found. Glazer and Konrad (1996) observe that individuals who make charitable donations to signal their status or wealth can raise total welfare if they fund public goods. In Denicolò (2008) a firm signals compliance costs are low by voluntarily over-complying with a regulation, thereby inducing stricter regulation that harms its competitors and possibly raises welfare. Leppämäki and Mustonen (2009) show that workers may contribute to open source software to signal their skill level, while it is well known that the signaling incentive to over-educate can raise welfare if education has positive externalities (Spence, 1973).

Finally, because we rule out other forms of direct communication of information the model best applies to experiential or hedonic attributes of new products, which by their nature are difficult to value before use. For example, technical units of quality are often difficult to interpret, as Kamenica (2008) points out ("How much more...would you be willing to pay for a flashlight that delivers 40 rather than 35 lumens of light?"). However, it should be noted that we do not require consumers to be completely ignorant of the value of a new version since the model can be interpreted as applying to the residual uncertainty that remains after consumers have received any information regarding new non-hedonic attributes.

The rest of the article proceeds as follows. Section 2 introduces the base model and section 3 establishes the existence of equilibria and discusses welfare results. Section 4 then presents two extensions: in the first the firm exerts observable effort to improve its distribution of innovations while in the second consumer learning about product quality is imperfect. Section 5 then concludes.

2 Model

A monopolist performs research and development (R&D) to improve the quality of an existing product. The outcome of the R&D process is stochastic, denoted by a and drawn from distribution F with log-concave density f and full support on $[\underline{a}, \overline{a}] \subseteq \mathbb{R}$.[4] The realization a is the net improvement over the existing quality, and in principle we allow for $\underline{a} < 0$, that is for some innovations to be harmful. Once an innovation is realized, the firm privately observes its value and makes a binary decision to adopt the innovation for a one-time fixed cost of $M > 0$ or leave the product unchanged, corresponding to $a = 0$. Captured in M are new product launch costs such as the cost to alter production facilities or marketing expenditures that inform consumers of the existence of the new product version, and for this reason we assume it is independent of the realization of a. After the adoption decision is made, the firm sells the product over the course of two periods, discounting second period profit by a factor $\delta \in (0, 1]$.

There is a continuum of consumers indexed by i, each with type v_i drawn from distribution G with support on $[0, \bar{v}]$, and $1 - G$ log-concave.[5] Consumers live two periods, and in each period have unit demand for the product with value $u_i = v_i + a$. In the first period consumers observe whether an innovation was adopted but not its realization, while in the second period each consumer becomes aware of the product's quality regardless of whether she purchased in the first period.[6,7] There is therefore no information value to purchasing, and in each period a consumer purchases if and only if her expected utility exceeds that period's price. Note also that consumers know $a = 0$ if no innovation is adopted and become uninformed only if the firm

[4]The assumption of log-concavity ensures that the conditional expectation $E[a|a > a^*]$ grows with a^* at a rate slower than one, which is useful for several ensuing arguments that require monotonicity.

[5]The log-concavity of $1 - G$ is a standard assumption that ensures a unique profit maximizing price that solves the first order condition.

[6]This may happen through word of mouth, online reviews, or through other means. The existence of a second period makes the value of adoption depend on the realized quality, which will support signaling in equilibrium. Because consumers' information in the second period does not depend on their actions in the first period, an equivalent formulation is that a new cohort of consumers arrives each period and lives just one period.

[7]Just as price and advertising may signal quality in a one-period setting in which some consumers are informed (Bagwell and Riordan, 1991; Linnemer, 2002), so too can the innovation signal, as shown in a previous version of this paper in which the role of second period informed consumers is replaced with a proportion of first period consumers informed of the firm's R&D outcome. The current model allows innovation signaling to be analyzed separately from price signaling.

introduces a new version of its product. This feature of the model differs from many other signaling games and simplifies its structure. Denote by μ a consumer's belief about the quality of the product, and by $q(p, \mu) = 1 - G(p - \mu)$ the quantity sold at price p given this belief. All seller costs outside those incurred in adopting the innovation are normalized to zero, thus after the innovation decision its single period payoff is $pq(p, \mu)$.

The solution concept is perfect Bayesian equilibrium, and we restrict attention to equilibria in which first period consumers draw inference about quality only from the adoption decision and not from the price. This assumption helps focus the discussion on the signaling value of adoption rather than how this value interacts with the signaling value of prices.

3 Equilibrium characterization and properties

> I'm actually as proud of the things we haven't done as the things I have done. Innovation is saying 'no' to 1,000 things. —Steve Jobs[8]

In this section we show that when consumers are initially uninformed of quality, a firm's binary decision to implement an R&D outcome or not involves a trade-off between inducing a "new product" premium in the first period by incurring new product launch costs and selling to consumers who will be fully informed of the product's value in the second period. For a low enough type a, the launch costs and potential decline in second period profits exceed the benefits conferred by the new product premium and thus the firm censors its R&D outcome. Though uninformed, first period consumers place a demand premium on new products because they know the firm needs to earn profits from informed consumers in the second period to recoup its product launch cost M.

[8]Gallo, C. (2011). *The innovation secrets of Steve Jobs. Insanely different: principles for breakthrough success.* New York: McGraw-Hill.

We begin by demonstrating that the equilibrium adoption strategy is a simple threshold policy a^* whereby a new version a is launched if and only if $a \geq a^*$. Let $\mu(z) \equiv E[a \mid a \geq z]$ be the expected quality of an innovation above z, $p(\mu) = \arg\max_p \; pq(p, \mu)$ be the profit maximizing price given belief μ, and $\pi(\mu) = p(\mu)q(p(\mu), \mu)$ be the maximized profit. We define $\bar{M}$ as the solution to $(1 + \delta)\pi(\bar{a}) - \bar{M} = (1 + \delta)\pi(0)$, and assume that $M \leq \bar{M}$ to allow for the possibility of innovation. Then the equilibrium is described as follows.

Proposition 1 *There exists a unique equilibrium with adoption, characterized by threshold innovation a^* which solves*

$$\pi(\mu(a^*)) + \delta\pi(a^*) - M = (1 + \delta)\pi(0). \tag{1}$$

A seller adopts if and only if $a > a^*$ and charges $p_1 = p(\mu(a^*))$ in the first period and $p_2 = p(a)$ in the second period, else the seller does not adopt and charges $p(0)$ in both periods. If the solution to (1) is $a^* \leq \underline{a}$ then all types adopt in equilibrium.

Proof In any equilibrium in which adoption occurs with positive probability, the belief μ about the quality of an adopted product is pinned down on the equilibrium path. The net payoff to adopting an innovation a is $\pi(\mu) + \delta\pi(a) - M - (1 + \delta)\pi(0)$, and because it increases in a the equilibrium must be a threshold. Also, because beliefs are unaffected by prices, the seller sets the optimal price $p(\mu)$ in each period given that period's belief μ. Finally to establish existence, observe that the left hand side of (1) is increasing in a^*. Then, for any $M \leq \bar{M}$ the left hand side of (1) exceeds the right hand side when evaluated at $\bar{a}$, and therefore either there exists an $a^* \leq \bar{a}$ which solves (1), or otherwise every type adopts. ■

Equation (1) implies that $\mu(a^*) > 0$, therefore a new product is on average of a higher quality than the original product. To see this observe that to the contrary, if $\mu(a^*) \leq 0$ (which also implies $a^* < 0$) then after adopting the threshold seller makes less profit in each of the two periods than he would have otherwise. Because the threshold type must improve his profits by M, this is a contradiction. Therefore there is a first period premium of $\pi(\mu(a^*)) - \pi(0) > 0$ when adopting. Because this premium accrues to every adopted innovation regardless of its true quality, there may be incentive to adopt some attributes of questionable value. We now discuss several adoption benchmarks and assess whether the seller adopts when these benchmarks are not met.

First, we consider the seller's decision if consumers are informed of quality, thus removing the incentive to signal. A threshold $\hat{a}$ is defined as the solution to

$$(1 + \delta)\pi(\hat{a}) - M = (1 + \delta)\pi(0), \tag{2}$$

so that $\hat{a}$ is the lowest attribute the seller is willing to adopt if consumers are perfectly informed of its quality. From (1) and (2) it can be seen that $a^* < \hat{a}$ since $\mu(z) > z$ for any z. We refer to any attribute $a < \hat{a}$ as *informed-suboptimal*. Next, we take the consumers' perspective and define an innovation as *trivial* if the new product price premium exceeds the value of the new attribute,[9] that is if $\Delta p \equiv p(\mu(a^*)) - p(0) > a$. Finally, we refer to a *schlimmbesserung* attribute ("improvement for the worse" (Rheingold, 2000)) as one in which $a < 0$, so that it is harmful even in the absence of adoption costs. In the following proposition, we demonstrate that attributes that are informed suboptimal, trivial, and even schlimmbesserung could be adopted in equilibrium.

Proposition 2 *There exist adoption costs $0 < M_s < M_t$ such that schlimmbesserung attributes are adopted if and only if $\underline{a} < 0$ and $M < M_s$, trivial attributes are adopted if and only if $M < M_t$, and informed suboptimal attributes are always adopted.*

[9]Note that while this definition involves a trade-off between attribute value and price, the marketing literature has generally defined a trivial attribute purely in terms of its value without consideration of price (e.g., Carpenter et al., 1994.)

Notwithstanding this, in any equilibrium new products are on average improved (i.e., $\mu(a^*) > 0$) and thus command a new product pricing premium.

Proof See the appendix. ■

Example 1 *To fix ideas suppose $a \sim U\left[-\frac{1}{2}, \frac{1}{2}\right]$, $v_i \sim U[0,1]$, and $\delta = 1$. For any threshold a this yields a first period belief $\mu(a) = \frac{1}{2}\left(a + \frac{1}{2}\right)$, an optimal price $p(\mu) = \frac{1}{2}(\mu + 1)$, and a resulting profit $\pi(\mu) = \frac{1}{4}(\mu+1)^2$. From (1) and (2) we obtain closed form solutions for the equilibrium threshold a^*, informed threshold $\hat{a}$, and new product premium Δp as follows:*

$$a^* = \frac{2\sqrt{80M+31} - 13}{10}, \qquad \hat{a} = \sqrt{1+2M} - 1, \qquad \Delta p = \frac{\sqrt{80M+31} - 4}{20}.$$

In Figure 1 it can be seen that $a^* < \hat{a}$ for all M for which there is adoption in equilibrium (i.e. for which $a^* < \frac{1}{2}$), thus informed-inferior attributes are always adopted. Furthermore, $a^* \leq \Delta p$ whenever $M < M_t = \frac{41}{144}$, thus for these adoption costs trivial attributes are always added. Finally, $a^* < 0$ whenever $M < M_s = \frac{9}{64}$, thus for these adoption costs schlimmbesserung attributes are added.

Aside from the aforementioned benchmarks, a natural question is how the equilibrium adoption decision compares to that of a social planner who wishes to maximize total surplus. In turn, to find the social planner's optimal adoption rule, we must first specify her degree of control after adoption. In particular, if the social planner controls both adoption and allocation then she adopts whenever $a \geq \frac{M}{1+\delta}$ and allocates the product to all consumers. However, if the social planner only chooses the adoption threshold, and thereafter the game proceeds as before, she will choose a different adoption threshold, trading off several factors. We now discuss these factors first from the perspective of the seller, and thereafter return to solve the social planner's problem.

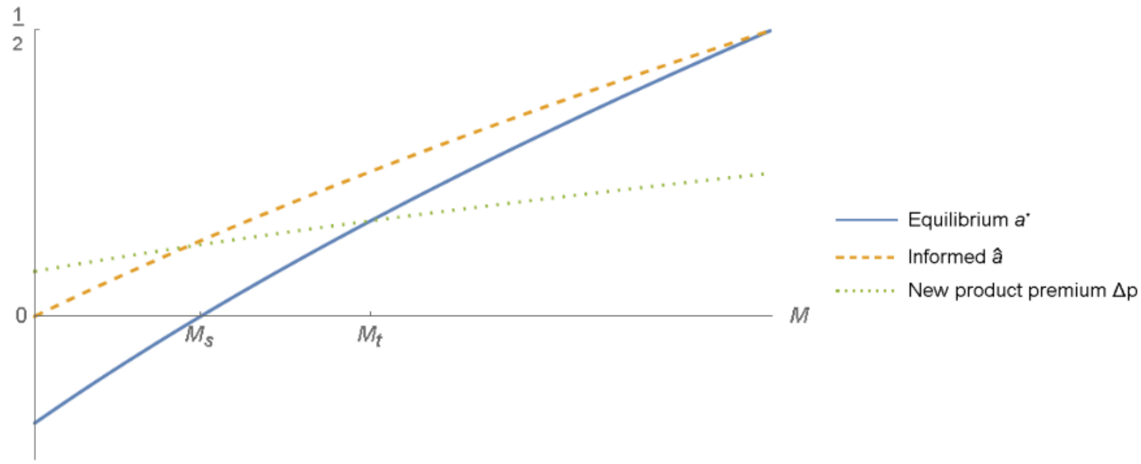

Figure 1: The equilibrium threshold a^* and informed threshold $\hat{a}$ as functions of the adoption cost M in Example 1, where $a \sim U\left[-\frac{1}{2}, \frac{1}{2}\right]$, $v_i \sim U\,[0,1]$, and $\delta = 1$. The value M_s is defined by $a^* = 0$ while M_t is defined by the new product price premium $\Delta p = a^*$.

Commitment and Information

The adoption of questionably valuable attributes in equilibrium stems from the fact that consumers overvalue the marginally adopted innovation a^* as $\mu(a^*)$. But is it optimal for the seller to adopt these questionable attributes from an ex-ante perspective? We now show that with commitment power the seller chooses less adoption and is strictly better off, and in absence of commitment the seller is better off in expectation when consumers are fully informed, which removes the new product premium.

Proposition 3 *Seller profits are strictly higher whenever he can commit to an adoption policy, and higher still if there is no commitment but consumers are fully informed about the realized attribute.*

Proof See the appendix. ■

Proposition 3 shows that the firm faces a commitment problem. Lower types impose a negative externality on all higher types: more significant improvements made to the product are not initially rewarded enough because consumers anticipate the firm occasionally introduces marginal or even trivial new products. Thus, when the marginal seller a^* induces an overestimate of its quality as $\mu(a^*)$, the profit from doing so comes not from misleading consumers but rather from reducing own profits for higher realizations. Because the seller is indifferent to adoption at a^* by definition, but hurts higher types by reducing $\mu(a^*)$, from an ex-ante perspective the seller would benefit by committing not to adopt.

The finding that the firm prefers facing informed consumers has useful implications for the disclosure of product quality. Although not modeled here, if the firm were capable of credibly disclosing its product's quality at no cost one can see through an unraveling argument that all quality types would disclose. Then since consumers will always be informed the full information threshold a would be used, resulting in higher firm profits. However, the implications for welfare are less clear, as discussed below.

The underinvestment problem

We have shown that the incentive to signal a "new and improved" product leads firms to adopt new attributes that in a full information environment do not justify the firm's product launch costs, and that may even be harmful. Given this result it might seem welfare must also be lower than if consumers could immediately learn the exact quality of a new attribute. However, even with full information the firm's adoption decision is already inefficient. As Arrow (1959) observed, a firm does not consider the gains to consumer surplus from adopting an innovation so it will tend to underinvest. Given this problem, we show that the signaling incentive to adopt a new innovation and receive a new product premium from uninformed consumers might on average lead to higher rather than lower efficiency.

We first establish the existence of the underinvestment problem under full information. In this setting let the single period consumer surplus be denoted by

$cs(a) \equiv \int_{p(a)}^{\bar{v}+a}(1-G(p-a))dp$ and ex-ante expected consumer surplus be

$$CS_I(z) \equiv F(z)(1+\delta)cs(0) \; + \; \int_z^{\bar{a}}(cs(a)+\delta cs(a))f(a)\; da$$

given adoption threshold z. Defining $\Pi_I(z)$ as the profit from using threshold z when consumers are informed (see equation 9 in the appendix), total ex-ante expected welfare is then $W_I(z) \equiv \Pi_I(z) + CS_I(z)$, and at the profit maximizing threshold $\hat{a}$ the marginal welfare is

$$\frac{dW_I}{dz}(\hat{a}) = \frac{d\Pi_I}{dz}(\hat{a}) + \frac{dCS_I}{dz}(\hat{a}) = 0 + f(\hat{a})(1+\delta)(cs(0)-cs(\hat{a})) < 0,$$

with the inequality following from $\hat{a} > 0$ whenever $M > 0$.[10] Therefore the social planner prefers an adoption threshold strictly smaller than $\hat{a}$ when consumers are informed.

Proposition 2 demonstrates that when consumers are uninformed the signaling incentive induces the equilibrium threshold a^* to be smaller than the informed threshold $\hat{a}$, therefore there is scope for improvement. However, welfare is not guaranteed to improve in the uninformed setting for two reasons. First, it is possible that a^* is so low that there is over-investment, potentially to an extent worse than the under-investment at $\hat{a}$. Second, even holding investment fixed there is a welfare cost when consumers are uninformed stemming from their inability to calibrate purchase decisions based on the true quality.

More formally, in the uninformed setting let $w(\mu) \equiv \pi(\mu) + cs(\mu)$ be the total surplus when consumers believe the investment is of quality μ and the seller prices

[10]Implicit in this argument is that $cs(\hat{a}) > cs(0)$ whenever $\hat{a} > 0$. This follows from the fact that $\frac{dp}{da} < 1$, which is established in the proof of Proposition 3.

accordingly, and define

$$W_U(z) \equiv F(z)(1+\delta)w(0) \;+\; \int_z^{\bar{a}} \Big(-M + w(\mu(z)) + \delta w(a) \Big) f(a)da \qquad (3)$$

as the expected welfare when a seller uses adoption threshold z and consumers are uninformed, believing the average quality is $\mu(z)$ in period one and a in period two. Thus we contemplate a social planner committing the firm to an adoption threshold, conditional on uninformed consumers' inferences and the firm's pricing decisions in the two-period model. In Proposition 4 we demonstrate that the uninformed setting is guaranteed to produce a higher welfare than the informed setting when adoption cost M is sufficiently high. Intuitively, this is because when product launch costs are sufficiently large, the Arrow underinvestment problem to be solved is severe and the firm is deterred from adopting marginal, welfare reducing innovations.

Proposition 4 *Welfare is higher when consumers are uncertain than when they are informed whenever M is sufficiently high.*

Proof See the appendix. ■

Returning to Example 1, Figure 2 demonstrates that there is a threshold adoption cost $\tilde{M} \approx 0.22$ so that for all $M < \tilde{M}$ welfare is higher in the informed setting, and for $M > \tilde{M}$ it is higher in the uninformed setting. In this example the maximal cost at which investment can be supported is $\bar{M} = \frac{5}{8}$, and therefore welfare is higher in the uninformed setting for the majority of feasible parameters. Also, at $\bar{M}$ welfare is the same across the two settings because indeed there is no uncertainty in either case.

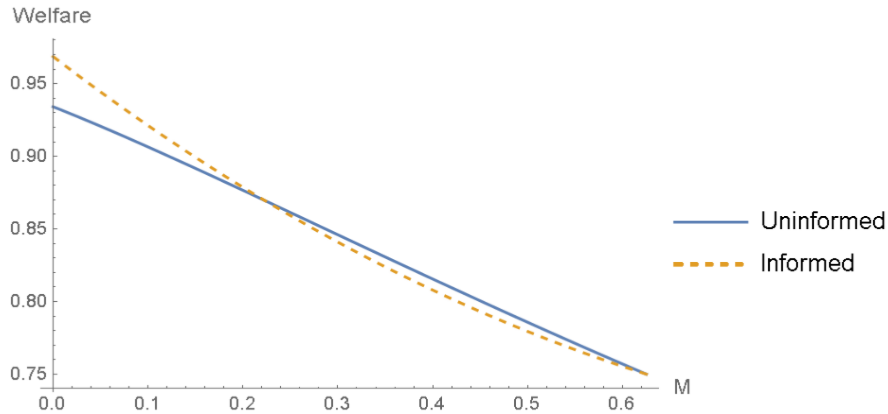

Figure 2: Welfare in the game (solid blue line) and in the benchmark full information case (dashed orange line) as a function of the adoption cost M in Example 1, where $a \sim U\left[-\frac{1}{2}, \frac{1}{2}\right]$, $v_i \sim U[0,1]$, and $\delta = 1$.

4 Extensions

4.1 Ex-ante investment to develop quality-enhancing innovations

We now consider an extension of the main model in which the firm makes an ex-ante investment to improve the R&D distribution, and ask how the innovation signal may affect the incentive for such an investment. Let $e \geq 0$ be a publicly observable effort level that incurs an increasing convex cost $C(e)$ with $C(0) = C'(0) = 0$, and results in an R&D outcome $a + e$, in which a is a stochastic component as before.[11] After e is chosen the continuation game proceeds as in Proposition 1.

We first argue that the underinvestment problem exists in this extended setting, both at the ex-ante investment and the subgame adoption decisions. To see this, consider the setting with fully informed consumers. In the adoption subgame we found the seller adopted too few innovations since he compares the cost M to the attribute's

[11]The public observability of R&D effort captures the fact that some firms are known for engaging in higher levels of R&D than others, and therefore their adoption decision generates a different inference.

marginal profit, while the social planner compares M to the sum of marginal profit and marginal consumer surplus. For the ex-ante investment decision, the seller equates the marginal cost of effort with the with the expected marginal profit across all realizations of a at which adoption occurs, while again the social planner equates the marginal cost with the sum of marginal profit and marginal consumer surplus for these realizations. Thus with informed consumers there is underinvestment in both decisions.

Our question, as in Proposition 4, is whether when consumers are uninformed the ensuing incentive to adopt more marginal attributes can alleviate the existing underinvestment problem. In particular, how does having uninformed consumers affect the ex-ante investment decision, and taken together with the innovation adoption decision, can welfare still be higher relative to the informed benchmark?

We first establish the effect of investment e at the adoption stage. For ease of exposition, we define the threshold in terms of the realization of the random variable a rather than the quality $a + e$. As in the previous analysis, when consumers are informed the adoption threshold $\hat{a}$ solves

$$(1 + \delta)\pi(\hat{a} + e) - M = (1 + \delta)\pi(0), \tag{4}$$

and when consumers are uninformed the adoption threshold a^* solves

$$\pi(\mu(a^*) + e) + \delta\pi(a^* + e) - M = (1 + \delta)\pi(0). \tag{5}$$

The following lemma describes how these thresholds are affected by the investment decision.

Lemma 1 *In any equilibrium with* $a^* \in (\underline{a}, \bar{a})$ *as defined in (5) and* $\hat{a}$ *as defined in (4),* $\frac{da^*}{de} < \frac{d\hat{a}}{de} < 0 < \frac{d(\mu(a^*)+e)}{de}$.

Proof See the appendix. ■

Lemma 1 serves dual purposes: it explains how ex-ante investment affects adoption, but also can be used to understand the ex-ante incentive to invest, and in particular whether this incentive is higher or lower depending on whether consumers are informed. When consumers are informed the seller's expected profit from investment e is

$$\Pi_I(e) = -C(e) + F(\hat{a}(e))(1+\delta)\pi(0) \; + \; \int_{\hat{a}(e)}^{\bar{a}} (\pi(a+e) + \delta\pi(a+e)) f(a) da,$$

with corresponding marginal

$$\frac{d\Pi_I}{de} = -C'(e) + \int_{\hat{a}(e)}^{\bar{a}} (\pi'(a+e) + \delta\pi'(a+e)) f(a) da. \tag{6}$$

In particular, the marginal revenue $\pi'(a+e)$ is integrated over every realization $a > \hat{a}$ at which adoption occurs. When consumers are uninformed the seller's expected profit is

$$\Pi_U(e) = -C(e) + F(a^*(e))(1+\delta)\pi(0) \; + \; \int_{a^*(e)}^{\bar{a}} (\pi(\mu(a^*) + e) + \delta\pi(a+e)) f(a) da,$$

with corresponding marginal

$$\frac{d\Pi_U}{de} = -C'(e) + \int_{a^*(e)}^{\bar{a}} \left(\pi'(a+e) \left(1 - \frac{d\mu}{da^*} \frac{da^*}{de} \right) + \delta\pi'(a+e) \right) f(a) da. \tag{7}$$

Compared to the margin in (6) for informed consumers, there are two countervailing effects. First, because the innovation is more likely to be adopted when consumers are uninformed (i.e. $a^* < \hat{a}$), the benefit of investment is more likely to occur. But second, because consumers anticipate a lower adoption threshold, the expected quality of a new product grows at a rate $\left(1 - \frac{d\mu}{da^*}\frac{da^*}{de}\right)$ smaller than one, so that the first period benefit accrues more slowly than in the informed case. The net effect is potentially

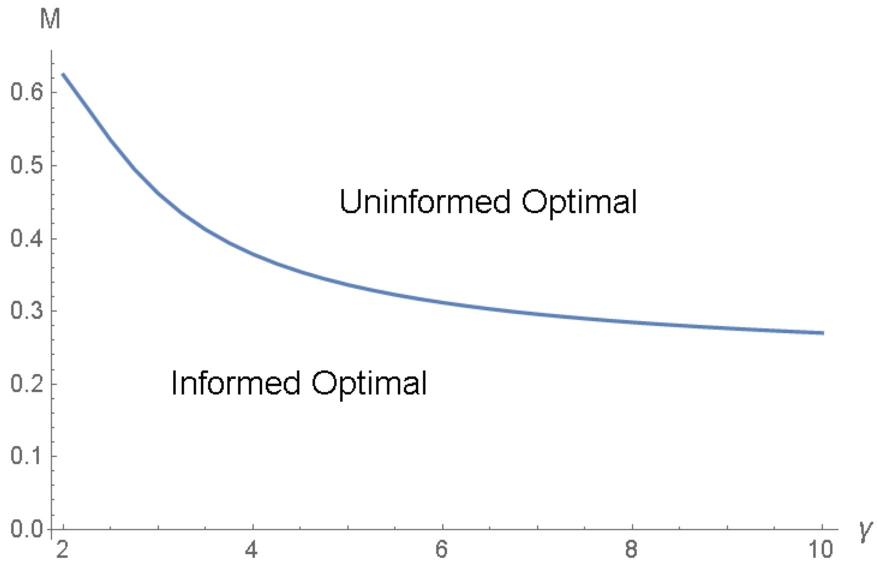

Figure 3: The welfare ranking of informed versus uninformed consumers by ex-ante investment and adoption cost parameter values (γ and M) in Example 2, in which $C(e) = \frac{\gamma}{2}e^2$.

ambiguous and it is possible that ex-ante investment is higher in the informed setting. We put together these observations in the ensuing numerical example.

Example 2 *Add an ex-ante investment stage to Example 1, with cost function* $C(e) = \frac{\gamma}{2}e^2$*. In Figure 3 we fix* $\delta = 1$ *and compute for each value of* γ *and* M *the equilibrium welfare when consumers are and are not informed. The boundary depicted in the figure shows parameters for which welfare is the same in the two regimes, with welfare higher in the uninformed regime above the boundary.*

From the fact that the boundary in Figure 3 slopes downward we can infer that ex-ante investment relatively benefits the informed regime over the uninformed one, while as established in Proposition 4 a higher M relatively benefits the uninformed regime. Overall, we see as before that the added adoption incentive in the uninformed regime improves welfare when investment and/or adoption costs are high, and therefore the Arrow underinvestment problem is more salient.

4.2 Imperfect learning

In the previous sections we assumed a simple learning structure that enabled all consumers to determine the value of the new product attribute after the first period. Learning occurred from personal consumption experiences or secondary sources such as word-of-mouth communications or product review websites, and consumers transitioned from totally uninformed in the first period to completely informed in the second period.

In principle learning can be imperfect with only some uncertainty about a product's quality resolved over time. Such products are of practical interest and lay along a continuum between two theoretical extremes: Nelson's (1970) experience good, for which all uncertainty is resolved after consumption, and Darby and Karni's (1973) credence good, for which the consumer learns nothing from consumption. In this subsection we allow for imperfect, or noisy, learning from consumption and other sources and show that the main results from the model with perfect learning generalize to this context. In addition, we develop managerially relevant insights regarding the effect noise has on profits and the quality of inferences consumers make about new products.

We operationalize noisy learning by assuming each consumer receives a common signal $x \equiv a + \epsilon$ after the first period that contains information about the realization of a as well as an independent mean zero error term ϵ whose distribution H is common knowledge. We assume f and h, the densities of a and ϵ respectively, are continuous with full support on $\mathbb{R}$ and h is log-concave so that consumers' posterior mean $E[a \mid x]$ increases in x.[12,13] Including a common error term is justified on the grounds that consumers, whether or not they made a first period purchase, may re-

[12] The assumption of full support simplifies the presentation of the results.

[13] Consumers' posterior mean is increasing in x when x and a are affiliated, a sufficient condition for which is the log-concavity of f and h (Milgrom and Weber, 1982). This ensures a unique attribute adoption threshold equilibrium exists.

ceive the same information from influential experts, product review websites, blogs, or word-of-mouth communication. For this reason we assume the firm observes the signal x as well.

We now characterize the equilibrium with imperfect learning and compare its properties to that found in Section 3 under perfect learning.

Proposition 5 *Let consumers learn about product quality from noisy signal $x = a+\epsilon$. Then the equilibrium characterization from Proposition 1 applies except that in period 2 all modified types charge the optimal price given the public signal x. This results in a lower attribute adoption threshold a^*, weaker innovation signal $\mu(a^*)$, and lower expected profits when learning is noisy than when it is perfect.*

Proof See the appendix. ■

We thus conclude greater noise exacerbates the frictions caused by asymmetric information. In particular consider the incentive of the marginal seller a^*. Whereas with perfect learning the true quality is revealed in the second period, with noisy learning the marginal seller expects an average belief strictly higher than a^*, and thus there is added incentive to adopt questionable attributes.[14] Consequently, in equilibrium there is a weaker signal associated with innovation. The lower adoption threshold hurts profits from an ex-ante perspective, exacerbating the seller's already existing commitment problem. Ex-ante profits also decrease because with less learning consumer posteriors are bunched more tightly in the second period, while the seller's profit is convex in the consumers' belief.

We thus demonstrate that an easier learning environment induces firms to apply a more stringent standard to releasing new products. While any new product initially enjoys a demand premium, products of marginal quality are quickly exposed in an easy learning environment, causing profits to be too low to justify product launch.

[14] For example, if second period learning is totally noisy, then when the true quality is a^* the second period belief is $E[a|a \geq a^*] > a^*$.

Thus the firm does not introduce such products in the first place but only does so when their quality is sufficiently high.[15]

The result that profits are lower in a more noisy learning environment has managerial relevance. Although a difficult learning environment may at least temporarily shroud a firm's products of marginal quality from being recognized as such, it also makes proving the value of high quality products more difficult. Even if the consumer of a high quality product has a positive experience with it, he knows that in a difficult learning environment experiences are more volatile and is wary of the low type products that exploit this fact. The proposition above tells us that on net firms benefit the easier it is for consumers to learn from their consumption experiences. Thus we find if the firm is able to ease the learning environment through product design or marketing communications it has incentive to do so.

5 Conclusion

This paper investigates firms' incentive to introduce improved products and the welfare implications of these improvements when consumers are uncertain of the quality of the improvement. We show that information is revealed by the very existence of a new product that has survived a firm's endogenous censoring rule so that product

[15] Metacritic.com co-founder Marc Doyle echoes this sentiment when he speculates that giving consumers better information will tend to encourage the release of higher quality movies and video games:

> Like many, we used to be suckered into seeing movies or buying games based on glowing review quotations in magazines or newspapers ("One of the year's best!") from critics nobody has heard of or from skilled PR department writers. A site like ours helps people cut through that unobjective promotional language. By giving consumers...information on the objective quality of a game, not only are they more educated about their choices, but it forces publishers to demand more from their developers, license owners to demand more from their licensees, and *eventually, hopefully, the games get better.*

Stuart, Keith (January 17, 2008). Interview: the science and art of Metacritic. *The Guardian.* http://www.guardian.co.uk/technology/gamesblog/2008/jan/17/interviewtheartofmetacriti "newness" alone signals higher quality on average and hence confers a pricing and demand premium.

This premium induces the firm to adopt attributes that would prove unprofitable had all consumers been informed. This fact has two main consequences. First, firms may sell a "new" product only trivially different from their older version in the sense that its improvement in performance does not justify its higher price. However, the greater the likelihood of such products the weaker will be the inferred value of the innovation signal, and it is shown this lowers the firm's ex-ante profits. The second consequence of a more lax attribute adoption policy is for welfare. By incentivizing the introduction of new versions, the innovation signaling effect can offset the existing monopoly underinvestment problem. For this reason it is possible that welfare can be lower when consumers are fully informed.

We show the robustness of these results by extending the model to a noisy learning environment in which consumers become better, though not perfectly, informed of the new product's value after the first period. We find the more difficult it is for consumers to learn a product's quality, the more incentive a firm has to introduce marginal improvements. Finally, an extension in which the firm takes effort to affect the distribution of R&D outcomes shows our welfare findings can survive in this setting. Potential extensions of the model include allowing the monopolist to concurrently sell the old and new versions of its product, and generalizing the model to an oligopoly context.

6 Appendix: proofs

Proof of Proposition 2 To see that $\mu(a^*) > 0$ must hold, suppose to the contrary that $\mu(a^*) \leq 0$. Then $a^* < 0$, and

$$\pi\left(\mu(a^*)\right) + \delta\pi\left(a^*\right) - M < \pi\left(\mu(a^*)\right) + \delta\pi\left(a^*\right) < \left(1+\delta\right)\pi\left(0\right),$$

since $M > 0$ and $\pi(\cdot)$ is increasing in its argument. However, this contradicts that type a^* must be indifferent to introducing a new product in a partially separating equilibrium and strictly prefer doing so in a pooling equilibrium.

Next, equation (1) implies an increasing equilibrium function $a^*(M)$ with $a^*(0) < 0$. Therefore there exists an M_s for which $a^*(M_s) = 0$ and for all $M < M_s$ schlimmbesserung attributes are added. For trivial attributes, note that

$$\frac{d}{da^*}(p(\mu(a^*)) - p(0) - a^*) = \frac{dp}{d\mu}\frac{d\mu}{da^*} - 1.$$

Observe that $\frac{dp}{d\mu} \leq 1$ because μ is a vertical demand shifter, and $\frac{d\mu}{da^*} < 1$ by the log-concavity of $1 - F$ (Theorem 6, Bagnoli and Bergstrom, 2005), and therefore $\frac{d}{da^*}(p(\mu(a^*)) - p(0) - a^*) < 0$. At adoption cost M_s we know that $a^* = 0$, and therefore $p(\mu(0)) - p(0) - 0 > 0$. Thus, there exists an $M_t > M_s$ so that for all $M < M_t$ trivial attributes are added. Finally, we show that $a^* < \hat{a}$ so that informed-suboptimal attributes exist. If $a^* > \underline{a}$ then from (1) and (2) it follows that $(1+\delta)\pi(\hat{a}) - M = \pi(\mu(a^*)) + \delta\pi(a^*) - M$. Since $\mu(a^*) > a^*$, if $a^* \geq \hat{a}$ then the right hand side of the expression would exceed the left, a contradiction. In the case that $a^* = \underline{a} < 0$ the desired inequality follows since $M > 0$ implies $\hat{a} > 0$ by (2). ∎

Proof of Proposition 3 First, under commitment the seller always has the option to induce the equilibrium outcome a^*, and therefore is at least as well off. To demonstrate that he is strictly better off, write the seller's ex-ante expected profit from choosing threshold z

$$\Pi(z) \equiv F(z)(1+\delta)\pi(0) \;+\; \int_z^{\bar{a}} (\pi(\mu(z)) + \delta\pi(a) - M) f(a)\, da,$$

and corresponding marginal profit

$$\Pi'(z) = f(z)\Big((1+\delta)\pi(0) - (\pi(\mu(z)) + \delta\pi(z) - M)\Big) + (1 - F(z))\frac{d\pi}{d\mu}\frac{d\mu}{dz}. \qquad (8)$$

Observe that $\Pi'(a^*) > 0$ because the first term of (8) equals zero by definition of a^*, and the second term is positive.

Next, denote the profit from using threshold z when consumers are informed as

$$\Pi_I(z) \equiv F(z)(1+\delta)\pi(0) \ + \ \int_z^{\bar{a}} (\pi(a) + \delta\pi(a) - M) f(a)\, da. \qquad (9)$$

First we observe that $\pi(\cdot)$ is convex. For this, note that $\pi'(a) = 1 - G(p(a) - a)$ (by the envelope theorem) and $\pi''(a) = g(p(a) - a)(1 - p'(a))$. Furthermore, that $p'(a) < 1$ follows from totally differentiating the first order condition with respect to price (with the arguments of $g(p-a)$ and $G(p-a)$ suppressed)

$$\frac{dp}{da} = \frac{g + pg'}{2g + pg'} = \frac{1 + \frac{(1-G)g'}{g^2}}{2 + \frac{(1-G)g'}{g^2}},$$

and observing that the ratio $\frac{(1-G)g'}{g^2} > -1$ by log-concavity of $1 - G$. Next, because $\pi(\cdot)$ is convex it follows from Jensen's inequality that

$$\int_z^{\bar{a}} \pi(\mu(z)) f(a) da < \int_z^{\bar{a}} \pi(a) f(a) da,$$

and therefore that $\Pi_I(z) > \Pi(z)$ for any threshold z.

Observe that when facing informed consumers the seller's adoption threshold $\hat{a}$ maximizes both ex-ante and ex-post profit (i.e. the adoption decision at $\hat{a}$ has no ex-ante impact on profits for other realizations of a), therefore it is as if the seller has commitment. Thus, by the preceding inequality, when facing informed consumers the seller can do at least as well as when facing uninformed consumers with commitment by simply mimicking the optimal strategy in the latter case. This implies that the maximized informed profit is larger than the maximized profit with commitment, which in turn is larger than the equilibrium profit $\Pi(a^*)$. ■

Proof of Proposition 4

Recall that welfare in the model is defined in equation (3), and we now write it as $W_U(M,z)$ to emphasize the dependence on M and adoption threshold z, as well as the fact that consumers are uninformed in the first period. In addition we now explicitly write

$$W_I(M,z) \equiv F(z)(1+\delta)w(0) \ + \ \int_z^{\bar{a}} \Big(-M + w(a) + \delta w(a) \Big) f(a)da \qquad (10)$$

as the expected welfare when a seller with adoption threshold z and consumers are informed about quality in both periods.

Also, recall that the equilibrium threshold a^* is the solution to equation (1) while full information threshold $\hat{a}$ is the solution to equation (2). Now, define $\bar{M} \equiv (1+\delta)(\pi(\bar{a}) - \pi(0))$ and observe that $a^*(\bar{M}) = \hat{a}(\bar{M}) = \bar{a}$. That is, when the adoption cost is $\bar{M}$ the seller with the highest possible realization $\bar{a}$ is indifferent to adopting, and because if he adopts his type is fully revealed, this seller would also be indifferent even if consumers were directly informed of the investment's realized value.

The welfare difference between the model's setting and one in which consumers directly observe the value of the investment is given by

$$\Delta W(M) \equiv W_U(M, a^*(M)) - W_I(M, \hat{a}(M)). \qquad (11)$$

$\Delta W(\bar{M}) = 0$ because at $\bar{M}$ no investment occurs in either setting. We now wish to show that $\frac{d\Delta W(\bar{M})}{dM} < 0$, so that a small decrease in M makes welfare higher when consumers are uninformed than when they are informed. For this, we first show that for decreasing M, a^* decreases more quickly than $\hat{a}$ at $\bar{M}$.

Claim 1 $\frac{da^*(\bar{M})}{dM} > \frac{d\hat{a}(\bar{M})}{dM}$.

Proof of Claim First it is useful to establish that $\mu'(\bar{a}) = \frac{1}{2}$. To see this,

$$\mu'(\bar{a}) = \frac{f(\bar{a})(\mu(\bar{a}) - \bar{a})}{1 - F(\bar{a})} = \frac{f'(\bar{a})(\mu(\bar{a}) - \bar{a}) + f(\bar{a})(\mu'(\bar{a}) - 1)}{-f(\bar{a})} = 1 - \mu'(\bar{a}) \quad \Leftrightarrow \quad \mu'(\bar{a}) = \frac{1}{2},$$

where the second equality follows from L'Hôpital's rule and the third equality follows since $\mu(\bar{a}) = \bar{a}$. Now, we totally differentiate (1) and (2) and obtain

$$\frac{da^*(\bar{M})}{dM} - \frac{d\hat{a}(\bar{M})}{dM} = \frac{1}{\pi'(\bar{a})(\mu'(\bar{a}) + \delta)} - \frac{1}{\pi'(\bar{a})(1 + \delta)} > 0,$$

where the inequality follows because $\pi'(\bar{a}) > 0$ and because $\mu'(\bar{a}) = \frac{1}{2}$. ■

We can now prove the proposition. First, the rate of change of welfare when consumers are uninformed is

$$\begin{aligned}\frac{dW_U}{dM} &= \frac{\partial W_U}{\partial M} + \frac{\partial W_U}{\partial a^*}\frac{\partial a^*}{\partial M} \\ &= -(1 - F(a^*)) + \frac{da^*}{dM}\Bigg(f(a^*)(1 + \delta)w(0) \\ &\quad - \Big(-M + w(\mu(a^*)) + \delta w(a^*)\Big) f(a^*) \;+\; \int_{a^*}^{\bar{a}} w'(\mu(a^*))\mu'(a^*)f(a)da \Bigg).\end{aligned}$$

Evaluated at $\bar{M}$, at which by definition $a^*(\bar{M}) = \bar{a}$, the above expression simplifies to

$$\frac{dW_U(\bar{M})}{dM} = -\frac{da^*}{dM} f(\bar{a})\Big((1 + \delta)(w(\bar{a}) - w(0)) - \bar{M} \Big). \tag{12}$$

Next, the rate of change of welfare when consumers are informed is

$$\begin{aligned}\frac{dW_I}{dM} &= \frac{\partial W_I}{\partial M} + \frac{\partial W_I}{\partial \hat{a}}\frac{\partial \hat{a}}{\partial M} \\ &= -(1-F(\hat{a})) + \frac{d\hat{a}}{dM}\Bigg(f(\hat{a})(1+\delta)w(0) - \Big(-M + w(\mu(\hat{a})) + \delta w(\hat{a})\Big)f(\hat{a})\Bigg).\end{aligned}$$

Evaluated at $\bar{M}$, at which by definition $\hat{a}(\bar{M}) = \bar{a}$, the above expression simplifies to

$$\frac{dW_I(\bar{M})}{dM} = -\frac{d\hat{a}}{dM}f(\bar{a})\Big((1+\delta)(w(\bar{a}) - w(0)) - \bar{M}\Big). \tag{13}$$

Putting together (12) and (13) yields

$$\frac{d}{dM}\left(\Delta W(\bar{M})\right) = \left(\frac{d\hat{a}(\bar{M})}{dM} - \frac{da^*(\bar{M})}{dM}\right) f(\bar{a})\Big((1+\delta)(w(\bar{a}) - w(0)) - \bar{M}\Big).$$

The first term in parentheses is negative by Claim 1. The second term is positive because

$$(1+\delta)(w(\bar{a}) - w(0)) - \bar{M} > (1+\delta)(\pi(\bar{a}) - \pi(0)) - \bar{M} = 0,$$

where the inequality follows because the increase in total surplus of investing at $\bar{a}$ exceeds the increase in seller profit, and the equality follows by definition of $\bar{M}$. Therefore, $\frac{d}{dM}\left(\Delta W(\bar{M})\right) < 0$ and there must exist a neighborhood below $\bar{M}$ in which welfare when consumers are uninformed is higher than when consumers are informed. ■

Proof of Lemma 1 The first two inequalities follow from totally differentiating (4) and (5), which yield $\frac{d\hat{a}}{de} = -1$ and $\frac{da^*}{de} = -\frac{1+\delta}{\mu'+\delta}$, and from the fact that $\mu' < 1$, which follows from the log-concavity of $1-F$ (Theorem 6, Bagnoli and Bergstrom, 2005).

The third inequality follows from

$$\frac{d(\mu(a^*)+e)}{de} = -\mu' \frac{1+\delta}{\mu'+\delta} + 1 = \frac{(1-\mu')\delta}{\mu'+\delta} > 0,$$

with the inequality again following from the log-concavity of $1-F$. ■

Proof of Proposition 5 We first show the equilibrium is characterized by an adoption threshold. When consumers hold belief μ for the quality of an adopted product in the first period and posterior function $\nu(x)$ for an adopted product with signal x in the second period, the payoff to adopting an innovation of quality a is $\pi(\mu) + \delta E_\epsilon[\pi(\nu(a+\epsilon))] - M$. This payoff increases in a because $\nu(\cdot)$ is an increasing function, and therefore the equilibrium must be in threshold strategies. To show the equilibrium is unique, define the consumer's posterior from observing signal x when the seller uses threshold a^* as

$$\nu(x|a^*) \equiv \frac{\int_{a>a^*} af(a)h(x-a)da}{\int_{a>a^*} f(a)h(x-a)da},$$

and observe that the equilibrium is characterized by

$$\pi(\mu(a^*)) + \delta E_\epsilon[\pi(\nu(a^*+\epsilon|a^*))] - M = (1+\delta)\pi(0). \tag{14}$$

We will argue that the left hand side of (14) is monotonically increasing.

Claim 2 *For any fixed ε the posterior $\nu(x = a^* + \varepsilon|a^*)$ increases in a^*.*

Proof of Claim The derivative $\frac{d\nu}{da^*} = \frac{\partial \nu}{\partial x}\frac{dx}{da^*} + \frac{\partial \nu}{\partial a^*}$ decomposes into two effects: the change in the posterior because it is being evaluated at a higher value of x, and the change in the posterior at a given x due to consumers expecting a higher threshold a^*. Because f and h are assumed log-concave, the random variables x and a are affiliated and $\frac{\partial \nu}{\partial x} \geq 0$ by Theorem 5 of Milgrom and Weber (1982). Also, explicit calculation yields $\frac{\partial \nu}{\partial a^*} \propto \int_{a^*}^{\infty}(a-a^*)f(a)h(a^*+\epsilon-a)da > 0$. Therefore, ν increases in a^*. ■

Using the result of this claim, it follows that $E_\epsilon[\pi(\nu(a^* + \epsilon|a^*))]$ increases in a^*, and because we know from before that $\mu(a^*)$ is also increasing, the entire left hand side of (14) is increasing and thus the equilibrium must be unique.

Next, we argue that the equilibrium threshold is lower when learning is noisy than when learning is perfect. Observe that for any x the posterior $\nu(x|a^*) \equiv E[a|a \geq a^*, x] > a^*$. Put more simply, consumers know that in equilibrium the true quality is a^* or higher, and with noisy learning always put some probability on outcomes higher than a^* for any observed x. Integrating over all realizations of x obtains $E_x[\pi(\nu(x|a^*))] > \pi(a^*)$. Therefore, with noisy learning the threshold is lower and thereby the innovation signal is weaker.

Finally, we show profits are lower under noisy learning. Let a_p^* and a_n^* be the equilibrium thresholds under perfect and noisy learning, respectively. Because $a_p^* > a_n^*$, by Proposition 3 it suffices to establish that expected profits are higher under perfect learning when the firm is committed to the threshold a_n^* than when learning is noisy. First period profits are equal in this case and second period profits are equal when $a < a_n^*$, thus we are left to compare second period profits when $a \geq a_n^*$. We wish to show

$$\int_{a_n^*}^{\infty} \pi(a) f(a) da \; > \; \int_{a_n^*}^{\infty} E_\epsilon[\pi(\nu(a+\epsilon|a_n^*))] f(a) da, \tag{15}$$

where the integrand on the right hand side is the profit of a firm of type a, with the expectation taken over ϵ, each inducing a posterior $\nu(a+\epsilon|a_n^*) = E[a|a > a_n^*, x = a + \epsilon]$. To proceed, rewrite the right hand side as profits integrated with respect to the distribution of induced posterior means. Every signal $\hat{x}$ induces a posterior $\hat{\nu} \equiv \nu(x|a_n^*)$, and the likelihood of this posterior is the likelihood of all realizations of $a + \varepsilon = \hat{x}$, denoted by $k(\hat{\nu}) = \int_{a_n^*}^{\infty} f(a) h(\hat{x} - a) da$. Gelman et al. (2013) demonstrates that the distribution over posteriors $k(\hat{\nu})$ is a mean-preserving contraction of the distribution over the original values $f(a)$, and because the function $\pi(\cdot)$ is convex the inequality in (15) obtains. ■

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