Reexamining the Schmalensee Effect

Jeong-Yoo Kim[*]   Nathan Berg

Kyung Hee University   University of Otago

March 20, 2017

Abstract

We reexamine the Schmalensee effect from a dynamic perspective. Schmalsensee's argument suggesting that high quality can be signaled by high prices is based on the assumption that higher quality necessarily incurs higher production cost. In this paper, we argue that firms producing high-quality products have a stronger incentive to lower the marginal cost of production cost because they can then sell larger quantities than low-quality firms can. If this dynamic effect is large enough, then the Schmalensee effect degenerates and, thus, low prices signal high quality. This result is different from the Nelson effect relying on the assumption that only the high-quality product can generate repeat purchase, because the result is valid even if low-quality products can also be purchased repeatedly. We characterize a separating equilibrium in which a high-quality monopolist invests more to reduce cost and, as a result, charges a lower price. Separation is possible due to a difference in quantities sold in the second period across qualities.

JEL Classification Code: D82, L15

Keywords: Experience Good, Quality, Signal, Schmalensee Effect

[*]This research was begun when the first author was visiting POSTECH in 2015. Corresponding author: Department of Economics, Kyung Hee University, 1 Hoegidong, Dongdaemunku, Seoul 130-701, Korea, (Tel) +822-961-0986, (Email) jyookim@khu.ac.kr

1   Introduction

Recently, a smartphone named Luna was launched in Korea. The retail price was $380, half the price of most premium phones—and it offered higher-quality specs than most of its mid-range peers, comparable to Samsung's earlier flagship product, the Galaxy S5. Luna's processor, the Snapdragon 801 by Qualcomm, supported a 2.5 GHz Quadcore while many mid-range smartphones such as BandPlay and the Grand Max by Samsung Electronics used the Snapdragon 410 with only a 1.2 GHz Quadcore. Luna's success and popularity have been attributed to its low production cost, which is due to a collaboration with Taiwanese manufacturing company, Foxconn. Luna's success also led to the perception that low-priced smartphones could have high quality.

Since the seminal work of Nelson (1970, 1974), it has been controversial whether a low or a high price better signals quality.[1] According to the longstanding economic wisdom, it depends on the comparison between two conflicting effects, the so-called Nelson effect and the Schmalensee effect. The Nelson effect occurs whenever high-quality firms have a stronger incentive to attract consumers than low-quality firms do because high-quality goods succeed at generating repeat purchases. On the other hand, the Schmalensee effect occurs whenever low-quality firms have a stronger incentive to attract consumers than high-quality firms do because doing so yields high profits due to a lower production cost. Therefore, the Schmalensee effect occurs only when the cost of producing high-quality products is greater than the cost of producing low-quality products.

The anecdotal example about Luna, however, raises questions about how relevant or realistic this assumption is. In fact, high profit margins would seem to be more valuable to high-quality firms because they can sell larger quantities that bring in more revenue than low-quality firms can. Therefore, a firm producing a high-quality product may have a stronger incentive to lower its marginal cost of production; consequently, the marginal cost of producing high-quality products may counterintuitively be lower than the marginal cost of producing low-quality products. The Schmalensee effect would then disappear or be reversed.

---

[1] To name only a few, see Wolinsky (1983), Milgrom & Roberts (1986), Bagwell & Riordan (1991), Judd & Riordan (1994), Daughety & Reinganum (1995), Kaya (2013) and Kim (2016).

In this paper, we reexamine the Schmalensee effect by formalizing this insight. Our main approach is to consider an extended model by incorporating the investment decision of the monopolist to lower the marginal cost rather than take the production cost as exogenous.[2] The above insight turns out to be correct. We show that under some sorting condition (that the cost-saving effect exceeds the demand-increasing effect), there is a separating equilibrium in which a high-quality monopolist invests more to reduce cost and, as a result, charges a lower price. Note that the result of signaling high quality by low price is not due to the Nelson effect. Although we consider a model of repeat purchase, the Nelson effect does not appear in our model because consumers can make repeat purchases of low-quality products as well. Our result comes from a cost difference that follows from a difference in the monopolist's investment decision. Although the difference in equilibrium investments to reduce marginal costs is due to a difference in sales in the second period when all uncertainty about quality is resolved, the difference in equilibrium prices does not rely on the assumption of repeat purchases as long as there is a cost difference across qualities. Therefore, the main driving force that separates a high-quality product from a low-quality one is the difference in the second-period sales. This difference in a low-quality-type- versus a high-quality-type firms' second-period sales leads to a difference in their incentives to invest and, therefore, to the crucial difference in marginal costs that drives our main result of low price being used as a signal of high quality.

A similar idea can be found in the literature on the contract theory. For example, Lewis and Sappington (1989) considers a screening model in which a monopolist has private information about its marginal cost and its fixed cost that is inversely related with the marginal cost.[3] This setup is similar to ours in the sense that a high fixed cost can be interpreted as an investment to reduce the marginal cost. However, in our model, the

_____

[2]None of the articles mentioned above considers the dynamic incentive to reduce the monopolist's cost of producing experience goods. Kaya (2013) analyzes a dynamic model of experience goods, but it is dynamic in the sense that the monopolist sets prices in a multi-period model. Chenavaz (2016) also considers a dynamic model. He assumes quality-improving innovation instead of cost-reducing innovation, and identifies the sales effect (roughly saying that high quality products are sold more) which is closely related to the insight behind the dynamic effect we identify. In this regard, Chenavaz (2016) is closer to ours.

[3]The literature calls this an adverse selection problem with countervailing incentives. See Maggi and Rodriguez-Clare (1995) for a more general model with countervailing incentives.

investment is a choice variable that determines the size of the marginal cost, whereas it is a fixed constant whose value is unknown in their model. Therefore, it is one of the main aspects to examine the firm's incentive to reduce the marginal cost in our model, while it is the main focus of their model to examine the firm's incentive to overstate or understate the true marginal cost.[4]

The article is organized as follows. In Section 2, we set up a model of an experience good. In Section 3, as a benchmark case, we consider the complete information case in which consumers are informed about the quality of the experience good. In Section 4, we consider the monopolist's joint pricing and investment decisions in the case of incomplete information. Concluding remarks follow in Section 5. All the proofs are provided in Appendix.

2 Model

We consider a monopolist who sells an experience good. The firm possesses private information about the quality of the good, whereas consumers do not. Let the quality of the good be r. Then, r is either H or L with $H > L$.[5]

The monopolist makes a cost-saving R&D investment K. Marginal cost is not exogenously given but endogenously determined by K. We will denote the monopolist's marginal cost by $c(K)$ where $c'(K) < 0, c''(K) > 0, \lim_{K \to 0} c'(K) = -\infty$ and $\lim_{K \to \infty} c'(K) = 0$.[6]

The interaction between the monopolist and consumers proceeds in three stages. At $t = 0$, the monopolist determines its investment level K, which is not observable to consumers. Then at $t = 1$, the monopolist chooses its first-period price, which is observable to consumers. Consumers then update their beliefs about the quality of the good and, based on their beliefs, choose either to buy one or not. Uncertainty about the quality of the good is resolved at the end of the period. Then, at $t = 2$, the firm chooses the second-period price and consumers make purchasing decisions.

---

[4]This is a more crucial distinction between our model and the model of Lewis and Sappington (1989) than whether it is a signaling model or a screening model.

[5]We could have denoted $\lambda \in (0,1)$ as the prior probability that the quality of the good is H, but this notation will not be used in this paper.

[6]Inada conditions characterized by these two assumptions on $c(K)$ are technical assumptions to ensure the existence of an interior solution for the optimal K.

We use $\pi(p, K; r)$ to denote the monopolist's profit when it chooses the investment K and the price p. It is formally defined by

$$\pi(p, K; r) = (p - c(K))D(p; r).$$

Here, $D(p, r)$ is the demand function for the good, where $D_1 \equiv \frac{\partial D}{\partial p} < 0$ and $D_2 \equiv \frac{\partial D}{\partial r} > 0$. For simplicity, we assume that $D(p) = r - p$.

The total profit of the monopolist (net of the investment cost) is defined by

$$\Pi(p_1, p_2, K; r) = \pi(p_1, K; r) + \pi(p_2, K; r) - K,$$

where p_t is the t-period price for $t = 1, 2$.

3   Complete Information

In this section, we consider the benchmark case of complete information in which consumers are fully informed about the quality of the good. To analyze this case, we will use backward induction.

Because price decisions at $t = 1, 2$ are the same under complete information, we simply consider the one-period price decision. Let $K^*(r)$ and $p^*(r)$ be the optimal investment level and the optimal price, respectively, of the monopolist producing a good of quality r.

At $t = 1$, for any given K, the optimal price of the monopolist is determined from the first order condition for profit maximization, implying that equilibrium price p^* must satisfy

$$\pi_p = D(p^*(r)) + (p^*(r) - c(K))D_1(p^*(r); r) = 0. \tag{1}$$

Taking account of the fact that it will choose $p^*(r)$ satisfying (1) in response to its own choice K, the monopolist will make its optimal R&D investment $K^*(r)$ to solve the following problem:

$$\max_K \Pi = 2\pi - K = 2(p^*(r) - c(K))D(p^*(r); r) - K. \tag{2}$$

Let $\pi^*(K; r) = \pi(p^*(r), K; r)$ and $\Pi^*(K; r) = \Pi(p^*(r), K; r)$. Then, by the Envelope Theorem, we have $\frac{d\pi^*(r)}{dK} = \pi_K$. Thus,

$$\frac{d\Pi^*(K)}{dK} = 2\pi_K - 1 = -2c'(K^*(r))D(p^*(r); r) - 1 = 0. \tag{3}$$

Equation (3) has the usual interpretation that an optimal investment must equate the marginal cost of increasing the investment to the marginal benefit from the increase through cost saving. The existence of $K^*(r)$ is guaranteed by the assumptions on $c(K)$ including the Inada conditions.

Assuming that the second order condition (i.e., $\pi_{KK} < 0$) of the monopolist's optimization problem holds, comparative statics lead to the following proposition.

Proposition 1 $K^*(r)$ *is increasing in* r *(i.e.,* $K^*(H) > K^*(L)$*).*

This proposition implies that a monopolist producing a high-quality good has an incentive to invest more in cost-saving R&D. Accordingly, the monopolist's marginal cost of producing a high-quality product could be lower than for a low-quality product (although the fixed R&D cost of producing a high-quality product is greater). The insight behind this result is exactly what is provided in the introduction. From the monopolist's point of view, the advantage of increasing its investment is to lower its marginal cost of production and thereby increase the mark-up (price over marginal cost) it earns on each unit sold. Because a high-quality monopolist can sell a larger quantity due to higher demand, the firm has a stronger incentive to invest in R&D than it would if it were a low-quality monopolist.[7] This confirms the insight in this model of complete information.

Now, we will examine the comparative statics of the pricing decision. From equation (1), we have

$$D(p^*, r) + (p^* - c(K^*(r)))D_1(p^*, r) = 0.$$

To see the effect of quality on equilibrium price, we differentiate the expression above with respect to r to get

$$\frac{dp}{dr} = -\frac{\overbrace{D_2}^{(+)} - \overbrace{c'\frac{\partial K^*}{\partial r}D_1}^{(+)} + \overbrace{(p^* - c(K(r)))D_{12}}^{=0}}{\underbrace{2D_1 + (p - c(K(r)))D_{11}}_{(-)}}. \tag{4}$$

---

[7]To elaborate, this is because an increase in K raises the high-quality monopolist's profit through a reduction in c. The reason is clear. If p is the same for both types of quality, then a high-quality firm is able to increase its demand more. If p responds optimally, then the high-quality firm's profit will be greater than a low-quality firm's profit.

The sign of the denominator comes from the second order condition. We cannot determine the sign of the numerator. Therefore, it is not clear whether $p^*(r)$ is increasing or decreasing in r.

Intuitively, there are two conflicting effects. On the one hand, since the demand for a higher-quality product is larger ($D_2 > 0$),[8] the equilibrium price rises as quality increases. On the other hand, since the marginal cost of a higher-quality product is lower, choosing higher quality thus lowers the price of high-quality products. Due to the (dynamic) second effect, the equilibrium price of a higher-quality product may be lower than the price of a lower-quality product.

Finally, it is clear that profits are increasing in the quality. Let $\pi^*(r) = \pi^*(K^*(r); r)$ and $\Pi^*(r) = \Pi^*(K^*(r); r)$. Then, Proposition 2 summarizes the result.

Proposition 2 *(i) $\pi^*(H) > \pi^*(L)$, and (ii) $\Pi^*(H) > \Pi^*(L)$.*

The intuition for (i) is quite obvious. The equilibrium profit of a high-quality monopolist is higher because consumer demand is greater and cost is lower due to the monopolist having made a larger investment. The intuition for (ii) is also clear. Although the high-quality monopolist incurs greater investment cost, it optimally chooses to make this larger investment because the return is higher. The profit of the high-quality monopolist (after netting out investment costs and the effects of strategic best-responses among consumers) is also greater. This proposition is essential to deriving our main result.

4   Incomplete Information

In this section, we will examine whether the result of different R&D investments carries over to the case in which the quality of the product is not known to consumers before they decide whether or not to purchase one.

If consumers are not informed of product quality, the monopolist's choice of price which consumers do observe may nevertheless reveal private information about product quality. Signaling games often involve many equilibria depending on posterior beliefs. It is therefore

---

[8]Mathematically, the second term of equation (4) disappears.

usual to use a stronger refinement than weak Perfect Bayesian Equilibria as a solution concept. In this section, we will use the C-K Intuitive Criterion developed by Cho and Kreps (1987) as the main solution concept.

4.1   The Second-Stage Pricing Game

Since the true quality of the good is revealed right before the second period, the analysis for the second-period price decision is the same as in the case of complete information. Thus, our main interest will be the price decision in the first period.

Given the marginal cost which was determined by the investment decision, the monopolist chooses its first-period price. Our main purpose is to investigate how prices can signal high quality. We therefore restrict attention to separating equilibria in which each type of monopolist charges a different price (what we will call "price-separating equilibria").

Let the investments made by a high-type monopolist and a low-type monopolist in the (price)-separating equilibrium be denoted as K_H and K_L.. For the time being, we will assume that K_H and K_L are simply given (and satisfy $K_H > K_L$) because the pricing decision is the main focus of this subsection. Note that the monopolist's private information about quality is not revealed at this stage (after the investment decision is made) even if $K_H > K_L$, because K is not observable to consumers.

Let the first-period prices of high-type and low-type monopolists be denoted as p_H and p_L in the separating equilibrium. Also, let $\pi(p, r, r^e)$ represent the profit of a firm with the true quality r and perceived quality r^e. We say that a weak Perfect Bayesian Equilibrium (p_H, p_L) passes the C-K Intuitive Criterion (IC) if there does not exist a price $p(\neq p_H, p_L)$ such that

$$(i) \quad \pi(p_L, L, L) \geq \pi(p, L, r^e), \quad \forall r^e = L, H, \tag{5}$$

$$(ii) \quad \pi(p_H, H, H) < \pi(p, H, H). \tag{6}$$

Roughly speaking, condition (i) implies that an off-the-equilibrium price p is equilibrium-dominated for type L. Condition (ii) implies that if consumers believe that the price p came from type H for which p is not equilibrium-dominated, the monopolist of type H will have an incentive to deviate to such a price p from p_H. If there exists a price satisfying

8

these two conditions, then (p_H, p_L) cannot be a reasonable equilibrium that passes the C-K Intuitive Criterion because the H-type monopolist has an incentive to deviate from the equilibrium. Note that the second-period profits cancel out so they cannot affect (5) and (6). This is because K is already determined and is, thus, unalterable—and the revelation of private information makes the monopolist choose $p^*(K; r)$ regardless of the first-period price decision for any $r = H, L$.

The following lemma will be useful in characterizing the separating equilibrium.

Lemma 1 *In any price-separating equilibrium, we have $p_L = p^*(L)$.*

This is clear because if $p_L \neq p^*(L)$, then the monopolist would profitably deviate to $p^*(L)$. Lemma 1 implies that in any (price)-separating equilibrium, it must be the case that $\pi(p^*(L), L, L) = \pi^*(L)$ in the first period.

We now demonstrate a separating equilibrium in which a monopolist signals high quality by choosing a low price. To avoid the trivial case, we assume that $\pi(p^*(H), L, H) > \pi(p^*(L), L, L)$, that is, the first-best outcome $(p^*(H), p^*(L))$ cannot constitute a separating equilibrium. This assumption implies that the low-quality firm can always imitate a high-quality firm if the high-quality firm charges $p^*(H)$.

If $K_H > K_L$, so that $c_H \equiv c(K_H) < c(K_L) \equiv c_L$, then separation is possible because the firm's profit depends not only on perceived quality but also on true quality through the difference in production costs. It is therefore costly for the low-quality type to mimic the high-quality type. Since we assume that such an undistorted outcome is not an equilibrium, the high-type firm must distort its price upward or downward to push the profit of the low-type firm below its maximum profit $\pi^*(L)$. In other words, p_H must satisfy the incentive compatibility constraint of the low-quality monopolist. The region that satisfies the low-quality monopolist's incentive compatibility constraint is illustrated in blue in Figure 1.

On the other hand, p_H must also satisfy the incentive compatibility of the high-quality monopolist. A high-type monopolist choosing to send a costly signal must have no incentive to deviate to its optimal price when it is perceived to be a low-quality type. The region satisfying the high-quality type's incentive compatibility constraint is illustrated in red in Figure 1.

Figure 1 shows that a high-quality type's separating price, which satisfies both types'

incentive compatibility conditions, can be distorted either upward or downward. In other words, high-quality products can be signaled either by high or low prices However, if the cost-reducing investment sufficiently improves efficiency such that the resulting reduction in marginal cost exceeds the increase in demand, then we can show that, in this case, high quality can be signaled only by a low price.

Proposition 3 *If $c_L - c_H > \Delta \equiv H - L$, then $p_H < p_L$ in the unique separating equilibrium that passes the C-K Intuitive Criterion where $p_H < p^*(H)$.*

The condition for the cost ($c_L - c_H > \Delta$)—which will be called separation condition (SC)—is crucial for signaling high quality via low price. This condition implies that the full-information price of an H-type monopolist is lower than that of an L-type monopolist. If the inequality of the condition is reversed, then high price signals high quality just as Schmalensee (1978) predicted.

The intuition behind this proposition goes as follows. If the optimal price for the H-type monopolist under complete information can be imitated by the L type, then the H-type's equilibrium price must be distorted either upward or downward to signal its quality. Can the monopolist not charge a higher price to signal high quality? The answer is negative because more distortion is required in the upward direction so long as $p^*(H) < p^*(L)$. Upward distortion is more costly for H type. Therefore, if the monopolist charges a lower price than the upwardly distorted equilibrium price, then consumers should believe that the monopolist is H type (for whom such a downward deviation is less costly) and not L type; in fact, the L type never gains by doing so. Hence, H type will not stick to its equilibrium price. This overturns the equilibrium involving upward distortion. This also confirms the insight that the high-quality monopolist is more likely to gain by charging a lower price and thereby increasing sales because of its higher margin ($c_L > c_H$).

Our result that high quality can sometimes be signaled only by choosing a low price is not due to repeat purchases. So long as the true quality type is revealed (e.g., through word-of-mouth communication) right after the first period, assumptions about repeat purchases have no role in this model. A high-quality monopolist's large sales volume achieved by offering a generously low introductory price in the first period does not, in our model, generate a large sales volume in the second period, which is determined independently of first-period

sales volume. Therefore, the results in the Propositions above are not due to the Nelson effect, but simply due to the low production costs of the high-quality product, contrary to the precondition of the Schmalensee effect.

We will examine the investment decision in the next subsection to see whether it is plausible that the cost of high-quality product is lower than the cost of low-quality products.

4.2 The First-Stage Investment Game

Let $\pi^{**}(r; K)$ be the r-type's profit (from the viewpoint of the first period, i.e., revenue net of investment costs K) in the separating equilibrium in the pricing game under incomplete information. That is, $\pi^{**}(r; K) = \pi(p_r, K; r)$. Assuming that the separating equilibrium is played in the subsequent game, the monopolist's investment decision will depend on $\pi^{**}(r; K)$. Denote the equilibrium investment of an r-type firm by K_r.

We are mainly interested in the possibility of the investment-separating equilibrium in which $K_H > K_L$. In order to have $K_H > K_L$ in equilibrium, two conditions must be satisfied: incentive compatibility conditions for investment decisions, and incentive compatibility conditions for separating prices (or equivalently, the SC condition).

Lemma 2 *In a separating equilibrium, $K_L = K^*(L)$.*

First, it is easy to see that any $K \neq K^*(L)$ cannot be an equilibrium investment level of the low-quality-type monopolist. If $K_L \neq K^*(L)$, then the low-quality-type monopolist would deviate to $K^*(L) = \arg\max \Pi^*(K; L) = 2(p^*(L) - c(K))(L - p^*(L)) - K$. Since K is unobservable, any deviant choice of K cannot affect consumer perceptions about quality. Some may wonder if a low-quality-type monopolist might benefit from deviating simultaneously from both $K^*(L)$ and $p^*(L)$. In the appendix, we will prove that payoff-improving deviations of this kind are not possible either.

Since K cannot be used as a signal due to its unobservability, separation by signaling is possible only by using the first-period price (i.e., $p_H = \bar{p}$ and $p_L = p^*(L)$). Therefore, the high-quality-type monopolist chooses K to satisfy

$$K = \bar{K}_H \equiv \arg\max_K \Pi^e(K) \equiv \pi(\bar{p}, K, H) + \pi(p^*(c(K)), K; H) - K \tag{7}$$

in a separating equilibrium.

Lemma 3 *In a separating equilibrium, $K_H = \bar{K}_H$.*

Similarly, if $K_H \neq \bar{K}_H$, then the high-quality-type monopolist has an incentive to deviate to $K = \bar{K}_H$ without reputational losses (i.e., without risk of being perceived as a low-quality type). Again, in the Appendix, we provide a proof showing that the high-quality-type monopolist has no incentive to deviate from $\bar{K}_H$ and $\bar{p}$ simultaneously.

It is clear that $K_L < K_H$ and, thus, it is possible to have $c_L \equiv c(K_L) > c(K_H) \equiv c_H$. Thus, if c_L and c_H satisfy the SC condition, we have a separating equilibrium in which high quality is signaled by low price.

Proposition 4 *There is a separating equilibriumin which $K_L < K_H$ and $p_H < p_L$ if the SC condition holds.*

This is our main result. It implies that the high-quality firm invests more than the low-quality firm does and thereby lowers its marginal cost to such an extent that it can signal high quality by choosing a sufficiently low price. This result uncovers a new dynamic aspect of quality signaling through price. Before we close this section, it is worth discussing an alternative assumption on the production cost. We may follow the spirit of Schmalensee (1978) more closely by assuming that the initial marginal costs of high-quality and low-quality types differ. Let the marginal cost be denoted by $c(K; r)$ where $c(0; r) = \bar{c}_r$ and $\bar{c}_H > \bar{c}_L$. We assume that $c(K; H) > c(K; L)$, $c'(K; r) < 0, c''(K; r) > 0, \lim_{K \to 0} c'(K; r) = -\infty$ and $\lim_{K \to \infty} c'(K; r) = 0$ for all K and for all r. For example, we can assume that $c(K; r) = \bar{c}_r - s(K)$ where $s'(K) > 0$ and $s''(K) < 0$.

If the cost-saving investment is efficient enough to reverse the cost disadvantage of H type, then our result remains unaffected. If the cost-saving investment is so inefficient that it can hardly change the order of $c(K_H; H)$ and $c(K_L; L)$, then it will not be an interesting case because K plays little role in the model in that case. Neither case adds much to our analysis.

5 Conclusion and Caveats

In this paper, we reexamined the Schmalensee effect by considering a dynamic model of an experience good that incorporates the monopolist's investment decision to reduce cost. We

confirmed our insight that a high-quality monopolist does indeed have a stronger incentive to lower cost if consumers are not well informed about the quality of the product. This result may explain the phenomenon by which a high-quality firm would seem to expend more effort to reduce cost, as in the example in the Introduction about the Luna mobile phone.

We must admit, however, that our result is not very robust. We simply identified the third effect other than two already well known effects, Nelson effect and Schmalensee effect in explaining the pricing behavior of an experience good monopolist. If producing a high-quality product requires much costly technology, the incentive to lower the cost alone may not revert the original cost disadvantage, as discussed in Section 4. Also, the third effect is possible only if the monopolist engages in a process innovation reducing the marginal production cost, not in a quality-improving innovation. Readers may wonder if this is a relevant setup in reality. According to White *et al.* (1988),[9] data seem to support the relevancy of our analysis at least weakly.

Appendix

Proof of Proposition 1: Total differentiation of equation (3) with respect to K and r yields $dK^*/dr > 0$, since $\pi_{KK} < 0$ from the second order condition and $\pi_{Kr} > 0$ from $D_2 > 0$. $\parallel$

Proof of Proposition 2: (i) Since $D_2 > 0$, $\pi(p, r)$ is increasing in r and so is $\Pi(p, K, r)$ for all p and K. Therefore, it is clear that $\Pi^*(H) \equiv \max_{p,K} \Pi(p, K, H) > \max_{p,K} \Pi(p, K, Lr) \equiv \Pi^*(L)$. (ii) Since $K^*(H) > K^*(L)$ by Proposition 1, it must be the case that $\pi(K^*(H), H) > \pi(K^*(L), L)$.

Proof of Proposition 3: Note that $p^*(H) < p^*(L)$ from the condition that $c_L - c_H > \Delta$. Figure 1 shows the set of separating equilibrium prices for the H-type firm. In the Figure, for

---

[9]It states that in the sample of British small firms, 61 per cent of product innovators were process innovators as well, while 52 per cent of those without new or modified products were process innovators. Most well known examples for cost-reducing process innovations include Ford and Precision Ring Makers (PRM). Ford's invention of the moving assembly line not only simplified vehicle assembly, but also saved the time and the cost to produce a single vehicle significantly. PRM developed low cost tooling techniques, so tooling changes for thin gauge shims cost about £30 with PRM's technique, while the cost when using conventional techniques was about £4000.

an equilibrium price $p_H < \bar{p}$, consider a slight deviation, price $p' = p_H + \epsilon < \bar{p}$, where $\epsilon > 0$. Then, a low-type firm X is worse off regardless of the posterior Belief, while a high-type firm X clearly benefits if it is perceived to be a high type. Since p' is equilibrium -dominated to a low-type monopolist, we can apply the intuitive criterion to infer that $r^e = H$. This leaves only the Riley outcome $(p_H, p_L) = (\bar{p}, p^*(L))$ involving the most efficient signaling as the equilibrium that passes C-K Intuitive Criterion. Now, for an equilibrium price $p_H > \underline{p}$, consider a slight deviation $p'' \in (\underline{p}, p_H)$. It also satisfies both (5) and (6). Therefore, it fails to pass IC. Finally, for $p_H = \underline{p}$, consider a deviant price $\bar{p}$. We can easily see that $\bar{p}$ is equilibrium -dominated for L because (i) $\pi(\bar{p}, L, H) = \pi^*(L)$ and (ii) $\pi(\bar{p}, L, L) < \pi^*(L)$. Also, we can see that $\pi(\bar{p}, H, H) > \pi(\underline{p}, H, H)$. This inequality follows from observing that (i) $\pi(p, H, H)$ is symmetric around $p = p^*(H)$ and (ii) $p^*(H) - \bar{p} < \underline{p} - p^*(H)$. (This also follows from $p^*(L) - \bar{p} < \underline{p} - p^*(L)$ and $p^*(H) < p^*(L)$ due to SC condition.) This implies that $p_H = \underline{p}$ does not pass IC. Therefore, the unique equilibrium that passes IC is $(p_H, p_L) = (\bar{p}, p^*(L))$. ‖

Proof of Lemma 2: It remains to show that a low-type monopolist has no incentive to imitate a high-type monopolist by choosing p_H and $K \neq K_L$. Since only the price is observable, this deviation will lead to $r^e = H$. If he deviates from K_L, we have

$$
\begin{aligned}
\frac{\partial \Pi(K; L)}{\partial K}\Big|_{K=K_L} &= \frac{\partial \pi(\bar{p}, L, K)}{\partial K} + \frac{\partial \pi^*(L, K)}{\partial K} - 1 \\
&= -c'(K_L)(H - \bar{p}) - c'(K_L)(L - p^*(L)) - 1 \\
&= -2c'(K_L)(L - p^*(L)) - 1
\end{aligned}
\tag{8}
$$

by using Envelope Theorem and $H - \bar{p} = L - p^*(L)$. Therefore, it follows from comparing equation (3) and (8) that $\frac{\partial \Pi(K;L)}{\partial K}\big|_{K=K_L} = 0$, i.e., the low-type monopolist has no incentive to deviate from K_L if $K_L = K^*(L)$. ‖

Proof of Lemma 3: Since $K_L = K^*(L)$ from Lemma 2, the low-quality monopolist's cost is $c(K^*(L))$. Let us fix $c_L \equiv c(K^*(L))$. Then, $\bar{p}$ is also fixed because it satisfies $\pi(\bar{p}, L, H, c_L) = \pi(p^*(L), L, L; c_L)$.

We already know from Section 4.1 that (p, K_H) cannot be a profitable deviation for the high type for any $p \neq \bar{p}$. Now, let us consider a deviation (p, K) for $p \neq \bar{p}$ and $K \neq K_H$. We use the most pessimistic belief: $r^e = L$ if $p \neq \bar{p}$ is observed. Then, the high-type monopolist

would choose K satisfying

$$K' = \arg\max_{K} \Pi^d(K) \equiv \pi(p^*(c(K)), K, L) + \pi(p^*(c(K)), K, H) - K. \qquad (9)$$

It is easy to see that $\Pi^e(\bar{K}_H) > \Pi^d(K')$, since $\pi(\bar{p}, K, H) > \pi(p^*(c(K)), K, L)$ for all K. Therefore, the high-type monopolist has no incentive to deviate to $p^*(c(K))$ and any $K \neq \bar{K}_H$. $\parallel$

References

[1] Bagwell, K.and M. Riordan, 1991, High and Declining Prices Signal Product Quality, American Economic Review 81, 224-239

[2] Chenavaz, R., 2016, Better Product Quality May Lead to Lower Product Price, BE Journal of Theoretical Economics, DOI 10.1515/bejte-2015-0062

[3] Cho, I. and D. Kreps, 1987, Signalling Games and Stable Equilibria, Quarterly Journal of Economics 102, 179-221

[4] Daughety, A. and J. Reinganum, 1995, Product Safety: Liability, R&D, and Signaling, American Economic Review 85, 1187-1206

[5] Judd, K. and M. Riordan, 1994, Price and Quality in a New Product Monopoly, Review of Economic Studies 61, 773-789

[6] Kaya, A., 2013, Dynamics of Price and Advertising as Quality Signals: Anything Goes, Economics Bulletin 33, 1556-1564

[7] Kim, J.-Y., 2016, Pricing an Experience Composite Good as Coordinated Signals, The Manchester Schoo, doi:10.1111/manc.12141

[8] Maggi, G. and A. Rodriguez-Clare, On Countervailing Incentives, Journal of Economic Theory 66, 238-263

[9] Milgrom, P. and J. Roberts, 1986, Price and Advertising Signals of Product Quality, Journal of Political Economy 94, 796-821

[10] Lewis, T. and D. Sappington, 1989, Countervailing Incentives in Agency Problems, Journal of Economic Theory 49, 294-313

[11] Nelson, P., 1970, Information and Consumer Behavior, Journal of Political Economy 78, 311-329

[12] Nelson, P., 1974, Advertising as Information, Journal of Political Economy 81, 729-754

[13] Schmalensee, R., 1978, A Model of Advertising and Product Quality, Journal of Political Economy 86, 485-503

[14] White, M., HJ Braczyk, A. Ghobadian, and J. Niebuhr, 1988, Small Firms' Innovation: Why Regions Differ, Policy Studies Institute

[15] Wolinsky, A., 1983, Price as Signals of Product Quality, Review of Economic Studies 50, 647-658.