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Low Quality as a Signal of High Quality

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Abstract If a product has two dimensions of quality, one observable and one not, a firm can use observable quality as a signal of unobservable quality. The correlation between consumers' valuation of high quality in each dimension is a key determinant of the feasibility of such signaling. A firm may use price alone as a signal, or price and quality together. Both signals tend to be used when the market is very uninformed, whereas price signaling alone tends to be used when the market is moderately informed. If high observable quality is inexpensive to provide, then it cannot signal high unobservable quality, and low observable quality is always an indication that unobservable quality is high.

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1 Introduction

Intuitively, it may seem that consumers who demand high quality will demand it in all dimensions. For example, a restaurant consumer who places a high value on high-quality food will probably also want high-quality service and a high-quality dining room. If quality is a normal good, differences in demand for quality of all kinds might be attributable to differences in income. We would then expect high-quality characteristics to be bundled together. However, this intuition fails for notable examples. Lower-quality beer is usually sold in bottles with screw-off caps (which are easier to open), while premium beer is not. Wine may be packaged in a bottle or in a plastic bag inside a box. The box (or "cask"), prevents air from mixing with the wine and thus keeps the wine fresh longer; in this sense, the cask can be regarded as the higher quality packaging. Only relatively low-quality wines are packaged in this manner; only the low-quality content is available in the high-quality (more convenient) packaging, and high-quality content is only available in the low-quality packaging. Newspapers can be sold in two formats, tabloid or broadsheet. The tabloid format is easier to handle, especially while riding a bus or a train. However, newspapers with high-quality content tend to be sold in the broadsheet format. Upscale hair-care products are only available at hair salons, while other brands can be purchased at grocery and drug stores. For many products and services, one must go to greater inconvenience to obtain higher quality.

In the above examples, high observable quality (e.g., packaging) is inexpensive and available to all firms, and it is not clear why some firms, particularly those that sell high unobservable quality (e.g., content), do not use it. In this paper, I examine the use of quality in an observable dimension to signal quality in an unobservable dimension. Someone buying an unfamiliar brand of beer might choose a bottle with a pry-off cap over a bottle with a screw-off cap without any direct knowledge of the content. That is, the consumer might choose the product that is of low quality in the only observable characteristic. This is a rational choice for the consumer if the packaging is a signal of the quality of the content. In fact, for such examples, the only possible reason for a firm to produce low-quality packaging is to signal the quality of the content.[1] Furthermore, it is not clear how the use of observable quality as a signal corresponds to other signaling models. The basic intuition of signaling offered by Spence (1973) is that, in order to be an effective differentiation device, a signal must be more costly to one type of agent. If a firm with high-quality content does not use high-quality packaging, it must be that a firm with low-quality content would face a different cost of using low-quality packaging. That is, there must be some incentive for the firm with high-quality content to use low-quality packaging that a firm with low-quality content would not have.[2]

The quality signaling literature has examined price as a signal of quality, either alone or in conjunction with other signals such as advertising.[3] In Bagwell and Riordan (1991), price alone can be used to signal unobservable quality. The high-quality firm's price is distorted upward from the full-information price in such a way that a low-quality firm would not mimic it. The lower quantity sold is more damaging to the low-quality firm (since the low-quality firm has a larger margin of price over marginal cost than the high-quality firm), and the low-quality firm loses sales to informed consumers by charging a higher price. Bagwell (1992) more generally considers the use of multiple signals to signal quality. The central result is that, if marginal costs are increasing in quality, a signal that reduces demand is more attractive to a high-quality

[1] This is true if, as in the examples, high-quality packaging is relatively inexpensive, in a sense stated explicitly in Section 2.

[2] Another reason for a firm to degrade quality is as a means of second-degree price discrimination, as in Deneckere and McAfee (1996). This is only possible if the firm offers at least two versions of its product.

[3] This literature includes Cooper and Ross (1985), Milgrom and Roberts (1986), Bagwell (1987), Bagwell and Ramey (1988), Wolinsky (1988), and Judd and Riordan (1994).

firm.[4]

The model presented here is related to that of Bagwell and Riordan (1991), and again the key issue is what kind of signal will not be mimicked by a low-quality firm. However, marginal production costs of high quality (in either dimension) have no direct bearing on the firm's choice of signaling regime. There is an opportunity cost if a firm lowers observable quality: consumers' willingness to pay for the product is lower. This cost is relatively low for a high-quality firm (a firm that produces high unobservable quality) if the correlation between consumers' valuations of high quality in each dimension is negative. For the beer example, this would mean that consumers who value high-quality content very highly are close to indifferent between the two kinds of packaging. Because this opportunity cost is higher for a low-quality firm, the high-quality firm does not have to distort price greatly to signal effectively. Quality signaling can then mitigate the distortion that arises from price signaling. There is the greatest incentive to use quality signaling if the market is very uninformed, when the distortion arising from price signaling is large. If the market is moderately informed, only price is used as a signal. When high observable quality is inexpensive to provide, only a high-quality firm will ever choose low observable quality. Thus, low observable quality is a sure sign that unobservable quality is high. Furthermore, high observable quality cannot be used to signal high unobservable quality.

In the following section, I introduce the model. In Section 3, I derive conditions for separating equilibria in the price-quality signaling game. In Section 4, I present a numerical example in which quality signaling is profitable. Section 5 concludes.

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[4] Engers (1987) also considers the use of multiple signals, generalizing the results of Spence (1973). When there are many unobservable quality attributes and potentially many signals, the cost of a signal must be decreasing in quality in order for the signal to be used.

2 The model

A product consists of two characteristics, one observable and the other unobservable. Let q_o and q_u be the respective qualities of the observable and unobservable characteristics. For the beer example, q_o is the packaging (type of bottle) and q_u is the content (the beer itself). In each dimension, the product may be of either high or low quality: $q_o \in \{L, H\}, q_u \in \{L, H\}$. All consumers observe q_o, but only informed consumers know q_u. There is a total mass of consumers M, and X is the ratio of informed to uninformed consumers. All consumers have a reservation utility of zero.

I assume that consumers are willing to pay α for low observable quality and that willingness to pay (WTP) for high observable quality is uniformly distributed on $[\alpha, \beta]$. Similarly, consumers are willing to pay γ for low unobservable quality, and WTP for high unobservable quality is uniformly distributed on $[\gamma, \delta]$. Let LH be a consumer's WTP for the bundle $(q_o = L, q_u = H)$ and HL a consumer's WTP for the bundle $(q_o = H, q_u = L)$. Given the above uniformity assumptions, LH is uniformly distributed on $[\alpha + \gamma, \alpha + \delta]$ and HL is uniformly distributed on $[\gamma + \alpha, \gamma + \beta]$.

I further assume that HH, the WTP for the bundle $(q_o = H, q_u = H)$, is uniformly distributed on $U[A, B]$, where $A \in [\alpha + \gamma, \beta + \gamma]$ and $B \in [\alpha + \delta, \beta + \delta]$. Note that this distribution is *not* taken to be the sum of the distributions for high quality in each dimension alone. For tractability, I am directly assuming that the distribution of WTP for HH is uniform, which is in effect an assumption about the nature of consumer utility.[5] The assumption coincides with additive separability in the cases of perfectly positive correlation of consumer WTP for high quality in each dimension, in which case the interval is $[\alpha + \gamma, \beta + \delta]$, and of perfectly negative correlation, in which case the interval is $[\beta + \gamma, \alpha + \delta]$. Formally, we could arrive at this distribution

[5] I also assume that utility is well-behaved in the following sense. Consider consumers i and j, with WTPs LH_i, LH_j, etc. If $LH_i \geq LH_j$ and $HL_i \geq HL_j$, then $HH_i \geq HH_j$.

by taking the sum of the distributions for high quality in each dimension and mapping it into a uniform. Clearly such a mapping exists, given that the distributions involved are well-behaved.

A single firm enters the market and observes q_u.[6] If $q_u = H$, the firm is called a "high-quality" firm. After observing q_u, the firm chooses q_o and sets price. All consumers observe price and q_o, and informed consumers observe q_u. Consumers then decide whether or not to buy. Uninformed consumers' belief that quality is high, given the price and observable quality, is $b(P, q_o)$, where $0 \leq b \leq 1$.

Low quality in either dimension has a marginal cost of zero. The respective marginal costs of $q_o = H$ and $q_u = H$ are c_o and c_u. I assume that $c_o < \min(\alpha, \beta - \alpha)$ and $c_u < \min(\gamma, \delta - \gamma)$. This guarantees that, in a full-information setting, a firm will always sell high quality in both dimensions if it has the option of doing so. For the beer example, this means that any firm would package the beer in screw-top bottles if all consumers knew the quality of the content, because the benefit of the packaging to any given consumer outweighs the cost to the firm. I further assume $\delta - \gamma > \beta - \alpha$: the difference between high and low quality is greater in the unobservable dimension. Then, in a full-information setting, if a firm could only produce high quality in one dimension, it would choose the unobservable. Firm profit is $\pi(q_o, q_u, b, P)$.

I refer to an equilibrium in which the high- and low-quality firms set different prices, but both firms set $q_o = H$, as a "price separating equilibrium," and an equilibrium in which firms set different prices and different observable qualities as a "price-quality separating equilibrium."

[6]If the firm chooses q_u, there would be the usual trade-off between the cost of attaining high quality (e.g., research and development cost) and the value of high quality (the additional expected profit). The only way in which this decision interacts with the signaling issue presented here is that the value of being able to provide $q_u = H$ depends on whether the firm will be able to signal this quality credibly.

3 Price and quality signaling

First consider the effect of price signaling only: $q_u \in \{L, H\}$ and $q_o = H$. Assume that both the high-quality and low-quality firms always produce high observable quality, as if low observable quality is not an option. The model then collapses to that of Bagwell and Riordan (1991). In any separating equilibrium, the low-quality firm sets $P_L = P(q_o = H, q_u = L) = \frac{\beta+\gamma+c_o}{2}$, the price that maximizes $\pi(q_o = H, q_u = L, 0, P)$. This gives the low-quality firm the greatest profit conditional on consumers' belief that unobservable quality is low. If the high-quality firm sets price P, the low-quality firm will mimic if $\pi(q_o = H, q_u = L, 1, P) > \pi(q_o = H, q_u = L, 0, P_L)$, i.e. if the profit gained by inducing the belief that unobservable quality is high is greater than the profit at the low-quality price. Otherwise, the low-quality firm prefers to set price P_L. The boundary of the region within which the low-quality firm will mimic the high-quality firm's price is the set of prices $\{P|\pi(q_o = H, q_u = L, 0, P_L) = \pi(q_o = H, q_u = L, 1, P)\}$, the larger parabola in Fig. 1. Looking at price as a function of X, the proportion of informed consumers, this set includes all P such that $P(X) = \frac{B+c_o}{2} \pm \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}\left(\frac{\beta+\gamma-c_o}{2}\right)^2}$. If the market is sufficiently informed, then there is no possibility of mimicry, and the high-quality firm will simply set the full-information monopoly price. This price is $P_{po}^m = P^m(q_o = H,\ q_u = H) = \frac{B+c_o+c_u}{2}$. If the market is less informed, the high-quality firm differentiates itself from the low-quality firm by setting price equal to $\overline{P}_{po}(X) = \frac{B+c_o}{2} + \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}\left(\frac{\beta+\gamma-c_o}{2}\right)^2}$. The intuitive criterion of Cho and Kreps (1987) restricts the set of equilibrium prices here and in the following proposition.[7] Details of the proof of the following proposition may be found in the appendix.

[7] The intuitive criterion specifies that if consumers observe a deviation from the equilibrium path that would benefit only one type of firm, consumers should believe that it was that type of firm that deviated. E.g., if consumers observe an action by a firm that would only benefit a high-quality firm, consumers believe that the firm is in fact high-quality.

Proposition 1 (Bagwell-Riordan) *If only price may be used as a signal of unobservable quality,* $P(q_o = H, q_u = H) = \max\left\{\overline{P}_{po}(X), P_{po}^m\right\}$ *and* $P_L = \frac{\beta+\gamma+c_o}{2}$ *are the only separating equilibrium prices satisfying the intuitive criterion.*

In a relatively uninformed market, the high-quality firm's price is distorted upward (from the full-information price). Uninformed consumers can infer from the higher price that $q_u = H$. The magnitude of the price distortion is larger as the market is less informed.

Next consider under what conditions the high-quality firm would signal using both price and observable quality. The firm now chooses q_o (packaging) after learning q_u (content). A high-quality firm might decide simply to set $q_o = H$ and set price at the full-information level; or to set $q_o = H$ and use price to signal the high unobservable quality; or to set $q_o = L$ and use both price and observable quality as signals of unobservable quality.[8] First I will establish necessary conditions for a separating equilibrium in which both price and quality are used as signals, and then I will examine the high-quality firm's incentive to use each signaling regime. The results will be proved in terms of the width of the interval $[A, B]$, which is the range of consumer WTP for the bundle of high quality in both dimensions. The results can then be related to the correlation between consumer willingness to pay for high quality in each dimension, given the following lemma (proved in the appendix):

Lemma 1 *The greater the correlation of consumer WTP for high quality in each dimension, the wider the interval* $[A, B]$.

Finding necessary conditions for a price-quality separating equilibrium is very similar to the preceding analysis. As above, in any separating equilibrium, the low-quality

[8] As I show below, there are no circumstances in which the firm would ever use observable quality, but not price, to signal unobservable quality. Also shown below, $q_o = H$ can never be used as a signal because the low-quality firm would certainly mimic it.

firm sets price to maximize profit conditional on consumers' belief that unobservable quality is low. The boundary of the region within which the low-quality firm will not mimic the high-quality firm if it is using both price and observable quality as signals of unobservable quality is the smaller parabola in Fig. 1. If the market is sufficiently informed, the high-quality firm can signal unobservable quality by setting the full-information price (for the given quality bundle), $P_{pq}^m = P^m\left(q_o = L,\ q_u = H\right) = \frac{\alpha+\delta+c_u}{2}$. For a less informed market, the high-quality firm must set price $\overline{P}_{pq}\left(X\right) = \frac{\alpha+\delta}{2} + \sqrt{\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}\left(\frac{\beta+\gamma-c_o}{2}\right)^2}$ to signal unobservable quality. Further details of the proof may be found in the appendix.

Proposition 2 *If both price and observable quality are used as signals of unobservable quality,* $P\left(q_o = L, q_u = H\right) = \max\left\{\overline{P}_{pq}\left(X\right), P_{pq}^m\right\}$ *and* $P_L = \frac{\beta+\gamma+c_o}{2}$ *are the only separating equilibrium prices satisfying the intuitive criterion.*

Turning to sufficient conditions, first note that, if the market is sufficiently informed (if $X \geq X_{po}^m$ in Fig. 1), the firm will produce $\left(q_o = H, q_u = H\right)$ and price this bundle at the full-information monopoly price. At $X = X_{po}^m$, the profit from price-only signaling is strictly greater than the profit from price-quality signaling ($\pi_{po} > \pi_{pq}$): π_{po} is the full-information monopoly profit for a high-quality bundle, whereas π_{pq} is the profit earned by selling a lower-quality bundle at a price above its full-information monopoly price. Since both sets of prices and profits are continuous in X, $\pi_{po} > \pi_{pq}$ for X close to X_{po}^m. Thus, when the market is moderately informed, price signaling is preferred to price-quality signaling. If price-quality signaling is used, it is used at the least informed end of the market. To show this, note that if price-quality signaling is preferred at X^*, it must be that $\frac{\partial \pi_{po}}{\partial X} > \frac{\partial \pi_{pq}}{\partial X} > 0$ for some range of X such that $X \leq X^*$. That is, for some range of X, the profit from price-only signaling must be increasing in X faster than the profit from price-quality signaling. This is the only way price-quality profit could surpass price-only profit at X^*. The proof of the following lemma shows that if $\frac{\partial \pi_{po}}{\partial X} > \frac{\partial \pi_{pq}}{\partial X}$ for some X^*, then $\frac{\partial \pi_{po}}{\partial X} > \frac{\partial \pi_{pq}}{\partial X}$ for all $X \leq X^*$.

Lemma 2 *If there exists $X^* > 0$ such that a price-quality separating equilibrium exists when $X = X^*$, then a price-quality separating equilibrium exists for all $X \in [0, X^*]$.*

If the market is relatively uninformed, the firm must distort price upward to prevent mimicry. Adding observable quality as a signal can mitigate this distortion. The high-quality firm will use observable quality as a signal if the price-quality distortion is sufficiently less than the price-only distortion. That is, if the firm must distort the price of $(q_o = H, q_u = H)$ a great deal more than it must distort the price of $(q_o = L, q_u = H)$, the firm will prefer to sell $(q_o = L, q_u = H)$. This is only true if the correlation between consumers' valuations of high quality in each dimension is sufficiently positive, as the following lemma establishes. The proof of the lemma shows that, if the correlation is sufficiently positive (and thus $B - A$ is sufficiently large), π_{po} is increasing in X faster than π_{pq}, i.e. that $\frac{\partial \pi_{pq}}{\partial X} > \frac{\partial \pi_{po}}{\partial X}$. This means that, as X decreases, profits from both price-only and price-quality signaling are falling, but the price-quality profit is falling faster. Therefore, price-quality signaling becomes less appealing relative to price-only signaling as the market is less informed. Since price-only signaling is preferred at the more informed end of the market, if $\frac{\partial \pi_{pq}}{\partial X} > \frac{\partial \pi_{po}}{\partial X}$, then price-quality signaling will never be used.

Lemma 3 *No price-quality separating equilibrium exists if the correlation between consumers' valuations of high quality in each dimension is sufficiently positive.*

Intuitively, if the correlation is strongly negative, consumers who value $q_u = H$ (high-quality beer) highly do not place much value on $q_o = H$ (convenient packaging for beer), and vice versa. Consumers always value $q_o = H$ at least as much as $q_o = L$;

but if the correlation is negative, those who value $q_u = H$ highly consider $q_o = H$ to be only slightly more valuable than $q_o = L$ (or, in the extreme, no more valuable than $q_o = L$). In this case, it is not very costly to the high-quality firm to lower q_o, since the consumers from whom the firm is extracting the most surplus (those who value $q_u = H$ highly) do not lose much utility when q_o is lowered. It is much more costly for the low-quality firm to lower q_o. The firm would then be selling $(q_o = L, q_u = L)$, which is not highly valued to anyone, and the informed consumers know this. It is relatively more costly for the low-quality firm to mimic price-quality signaling than to mimic price signaling. Thus, the price distortion under price signaling is relatively greater, which gives the high-quality firm greater incentive to use price-quality signaling.

Two more conditions are necessary to obtain sufficiency. If $\beta - \alpha$ is small, the low-quality firm has too much incentive to mimic a quality signal. This is because $q_o = H$ is not much better than $q_o = L$, and so lowering q_o does not decrease consumers' willingness to pay much. Because of the incentive of the low-quality firm to mimic, a price-quality separating equilibrium would have to involve a greatly distorted price. This makes price-quality signaling unprofitable to the high-quality firm relative to price-only signaling, which precludes the existence of a price-quality separating equilibrium. If $\delta - \gamma$ is large, the low-quality firm again has too much incentive to mimic a quality signal. This is because there is so much to gain from successful mimicry: uninformed consumers place a high value on the perceived unobservable quality ($q_u = H$ is much more valuable than $q_u = L$). As above, this precludes the existence of a price-quality separating equilibrium. The following proposition gives the complete set of sufficient conditions. This is established by showing that $\pi_{pq} > \pi_{po}$ at the extremes of the conditions below and using continuity to argue that $\pi_{pq} > \pi_{po}$ is still true as we back away from the extremes. The following section contains an example of a set of parameters for which a price-quality signaling equilibrium exists.

Proposition 3 *A price-quality separating equilibrium exists if:*

(*i*) *the correlation between consumers' valuation of high quality in each dimension is sufficiently negative or not too strongly positive;*

(*ii*) *the market is sufficiently uninformed;*

(*iii*) $\beta - \alpha$ *is sufficiently large; and*

(*iv*) $\delta - \gamma$ *is sufficiently small.*

Figure 1 depicts a price-quality signaling equilibrium. The high-quality firm's price is represented by the heavy line. There is a discontinuity in the high-quality firm's price at X^*_{pq}. This is the point at which the firm switches between price-only and price-quality signaling.

Without specifying the full set of pooling equilibria, we can note that one kind of pooling equilibrium cannot exist:

Proposition 4 *Using the divinity criterion to refine consumer beliefs, there exists no equilibrium in which the high- and low-quality firms set the same price and* $q_o = L$.

If there were such an equilibrium, each type of firm would have incentive to deviate by raising q_o. By assumption, the difference between the additional value to the consumer and the additional cost to the firm is large enough to make such a deviation profitable. The only reason a firm would not want to set $q_o = H$ would be if this changed consumer beliefs about q_u unfavorably. Such an inference cannot be part of any reasonable set of consumer beliefs, according to the divinity criterion of Banks and Sobel (1987).[9] Therefore, there can be no pooling at $q_o = L$. It may be possible for there to be pooling at $q_o = H$, and it is certainly possible for each type of firm

[9] One implication of the divinity criterion is that consumers observing an action that would be profitable to either type of firm will not infer anything about the firm's quality from the action. E.g., if it is profitable for either type of firm to use high-quality packaging, consumers will not update their beliefs when they observe high-quality packaging. Unlike the divinity criterion, the intuitive criterion makes no restriction on beliefs about deviations that would benefit either type. Thus, although both criteria are in the same spirit, the divinity criterion is necessary to prove the proposition.

to set $q_o = H$ but different prices (this is the case when $X^*_{pq} \leq X \leq X^m_{po}$ in Fig. 1). In all of these equilibria, only the high-quality firm ever sets $q_o = L$. Even if there is a multiplicity of pooling and separating equilibria, consumers can always infer that unobservable quality is high if observable quality is low.[10]

A straightforward extension of the preceding results is the following:

Proposition 5 *There exists no separating equilibrium in which high observable quality signals high unobservable quality.*

That is, there is no set of prices $P_H(q_o = H, q_u = H)$, $P_L(q_o = L, q_u = L)$ constituting a separating equilibrium. The marginal cost of $q_o = H$ is low in the sense that a firm would always set $q_o = H$ under full information. If the high-quality firm uses high observable quality as a signal, the low-quality firm has no reason not to mimic it. The low-quality firm would then have a product of (weakly) higher value to consumers in addition to inducing the belief that its unobservable quality is high.

Proposition 5 holds for any degree of correlation, but it is not categorically true if the marginal cost of high observable quality is high relative to its value to some consumers. Consider a restaurant, where the dimensions of quality are food (unobservable) and decor (observable). This example is different from the motivating examples for this paper in that high observable quality is costly to provide. This higher cost decreases the incentive for a firm to provide high observable quality, unless there is a positive correlation of consumer preferences between the two dimensions of quality. In the case of a restaurant, this would mean that consumers who value high-quality food also value high-quality decor. It could be that high quality signals high quality in such a case. It would not be worth it for the low-quality firm to mimic the high-quality firm by providing high observable quality if this quality comes at a

[10]This is assuming that the hypotheses of the model hold. In particular, the difference in cost between high and low observable quality cannot be too large: $c_o < \min(\alpha, \beta - \alpha)$.

high cost and is not of significant value to those consumers willing to consume low unobservable quality. On the other hand, the marginal cost itself can be the decisive factor; apart from informational issues, a low-quality firm may not have incentive to provide high observable quality. In either case, when the marginal cost of observable quality is high (contrary to the model presented here), we would expect like qualities to be bundled together.

4 A numerical example

Consider again the beer example, where bottles with screw-off caps are considered to be the high-quality packaging, and bottles with pry-off caps are low-quality. Several facts can easily be observed casually in the market for beer in the U.S.: some brands of beer are packaged in bottles with screw-off caps, while others are packaged in bottles with pry-off caps; and brands that use the pry-off cap are more expensive than average. If we assume that higher price is associated with higher quality, it is not the case that all high-quality beers are packaged in bottles with pry-off caps. However, all brands that are packaged in bottles with pry-off caps are high-quality. Furthermore, brands in pry-off bottles tend to be imports and microbrews that sell at a smaller scale than national brands. It is not clear how the results of this paper would change if the model took into account competition among beer producers.[11] Nevertheless, given the convenience of the screw-off bottle, it is difficult to fathom why not all bottled beer is packaged in this manner, unless the packaging is being used as a signal of the quality of the beer itself.

To see how this example could fit into the model, consider the following set of parameters: $\alpha = 2$; $\beta = 4$; $\gamma = 2$; $\delta = 10$; $c_o = 1$; and $c_u = 1$. These values imply that the screw-off cap is superior, but high-quality beer is superior to low-quality

[11] Unfortunately, incorporating competition renders the model intractable.

beer to a greater degree. The marginal costs of packaging are assumed to be the same; if the cost of the screw-off cap is significantly higher, then we would expect the screw-off cap to be bundled with high-quality beer. Assume that $A = \beta + \gamma = 6$ and $B = \alpha + \delta = 12$. This corresponds to the lowest correlation possible: willingness to pay for quality in each dimension is perfectly negatively correlated. For these parameters, if $X < .28$, then $\pi_{pq} > \pi_{po}$ (using the profit expressions in Section 6.6); i.e., profit for a high-quality beer producer is greater using price-quality signaling. If $X > .61$, neither price nor quality is used as a signal, and for $.28 < X < .61$, price alone is used as a signal. This means that a given variety of high-quality beer will be sold in pry-off bottles if less than 28% of the potential consumers of that variety are aware of the quality. Thus, where the market is sufficiently uninformed, which is more likely to be the case for a microbrew or an import, high-quality beer is sold in a bottle with a pry-off cap. However, even for a high-quality beer, if the market is sufficiently informed, the beer will be sold in a bottle with a screw-off cap.

The assumption about correlation means that those consumers who place the highest value on the quality of the beer place the lowest value on the quality of the packaging, and vice versa. This would mean that those who value high-quality beer do not care about the benefits of the screw-off bottle, and those who find the screw-off bottle valuable are undiscriminating about the quality of the beer itself. A similar result holds for a less extreme correlation: if $[A, B]$ is somewhat wider than $[\beta + \gamma, \alpha + \delta]$, packaging is still used as a signal if the market is sufficiently uninformed. For example, if $A = 5$ and $B = 13$, price-quality signaling is more profitable if $X < .19$.

5 Conclusion

For products that have an observable dimension of quality and an unobservable dimension of quality, a firm may lower the observable quality as a means of signaling unobservable quality. A firm may engage in quality signaling even when price alone can signal quality. When price alone is used as a signal, the high-quality firm raises price above the full-information level. This distortion allows the high-quality firm to differentiate itself from the low-quality firm. If both price and quality are used as signals, the price is still distorted above the corresponding full-information price. However, the price-quality distortion may be lower than the price-only distortion, and price-quality signaling may be more profitable. If quality signaling is used, it is used when the market is very uninformed. This is where the distortion of price away from the full-information level is greatest, and the firm has the most to gain from adding quality as a signal. In a moderately informed market, price alone is used as a signal.

Quality signaling is used only if the correlation between consumer valuations of high quality in each dimension is not strongly positive. In this case, if the high-quality firm lowers observable quality, the total value of the product does not change much. It is relatively costly for the low-quality firm to mimic the quality signal (by producing low quality in both dimensions) because of the loss of sales to informed consumers. In this case, quality signaling is attractive to the high-quality firm. If there were no need to signal unobservable quality, observable quality would always be high, since it is relatively inexpensive for the firm to provide and is weakly preferred by consumers.

In some cases, there are both observable and unobservable dimensions of quality, but all firms produce high observable quality. This will happen if the correlation is sufficiently positive and the difference in cost for high and low observable quality is not drastic. Then, apart from signaling issues, it is always in a firm's interest to provide high observable quality. In other cases, when high observable quality is costly to provide, like qualities may be bundled. This would particularly be true if there is a positive correlation between consumer valuation of high quality in each dimension. Thus, the intuitive notion that the various attributes of a single product should be of similar quality holds in many cases but fails in others.

6 Appendix

6.1 Proof of Proposition 1

In any separating equilibrium, P_L must be such that $b(P_L) = 0$. The greatest profit the low-quality firm can earn is at the price $P_L = \max_P \{\pi (q_o = H, q_u = L, 0, P)\}$. This price is $P_L = P(q_o = H, q_u = L) = \frac{\beta+\gamma+c_o}{2}$. Any other price fails the intuitive criterion. The set $\{P|\pi (q_o = H, q_u = L, 0, P_L) = \pi (q_o = H, q_u = L, 1, P)\}$ defines the boundary of the region within which the low-quality firm would find it profitable to mimic the high-quality firm's price. Given that consumer valuation of the bundle $(q_o = H, q_u = L)$ is uniformly distributed on $[\alpha + \gamma, \beta + \gamma]$, $\pi (q_o = H, q_u = L, 0, P_L) = M(P_L - c_o)\left(\frac{\beta+\gamma-P_L}{\beta-\alpha}\right) = \left(\frac{M}{\beta-\alpha}\right)\left(\frac{\beta+\gamma-c_o}{2}\right)^2$. When $q_o = H$ and $b(P) = 1$, uninformed consumers believe the bundle being sold is $(q_o = H, q_u = H)$; consumer valuation of this bundle is uniformly distributed on $[A, B]$. The profit from selling only to uninformed consumers is $\pi (q_o = H, q_u = L, 1, P) = \left(\frac{M}{1+X}\right)\left(\frac{B-P}{B-A}\right)(P - c_o)$. We can later verify that informed consumers will not buy from the low-quality firm at any price that is part of a separating equilibrium. Setting $\pi (q_o = H, q_u = L, 0, P_L) = \pi (q_o = H, q_u = L, 1, P)$, we obtain a quadratic expression in P, the solution of which is $P_{po}(X) = \frac{B+c_o}{2} \pm \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}\left(\frac{\beta+\gamma-c_o}{2}\right)^2}$. Let $\overline{P}_{po}(X)$ be the positive root of $P_{po}(X)$, and note that $P_{po}(X)$ only exists if $X < \overline{X}_{po}$, where $\overline{X}_{po} = \frac{(B-c_o)^2(\beta-\alpha)}{(B-A)(\beta+\gamma-c_o)^2} - 1$. For $X < \overline{X}_{po}$, it is straightforward to establish that $\pi (q_o = H, q_u = L, 0, P_L) < \pi (q_o = H, q_u = L, 1, P)$ for prices inside the parabola defined by P_{po}; this is the region in which the low-quality firm will mimic the high-quality firm. Define X_{po}^{m} by $P_{po}\left(X_{po}^{m}\right)=P_{po}^{m}$. For $X>X_{po}^{m}$, only P_m satisfies the intuitive criterion. For $X<X_{po}^{m}$, any price P such that $P\neq P_{po}(X)$ fails the intuitive criterion. Furthermore, given $c_u>0$, only $\overline{P}_{po}(X)$ satisfies the intuitive criterion. The low-quality firm will not mimic the high-quality firm for any price $P=P_{po}(X)$, but because the cost of $q_u=H$ is positive, the high-quality firm earns greater profit by setting $P=\overline{P}_{po}(X)$.

6.2 Proof of Lemma 1

Let ρ be the correlation between LH and HL. Consider an observation a from the distribution LH, where $a>E(LH)$. Let $b_1=E(HL|a)$ when $\rho=\rho_1$, and let $b_2=E(HL|a)$ when $\rho=\rho_1+\varepsilon$, where $\varepsilon>0$. A straightforward implication of the properties of correlation is that $b_2>b_1$. If we repeat this exercise for some a such that $a<E(HL)$, then $b_2<b_1$. Now consider the effect on the distribution of HH of an increase in ρ. Since we know that $E(HL|a)$ increases for every $a>E(LH)$ and $E(HL|a)$ decreases for every $a<E(LH)$, and given the properties of the distributions described in footnote 5, an increase in correlation shifts mass in HH away from the mean. Given that this distribution is constrained to be uniform, the only way to accommodate mass shifting away from the mean of the distribution is for the range of the distribution to be wider. A similar argument demonstrates that mass in HH shifts toward the mean when the correlation decreases, and thus the range of the distribution must be narrower.

6.3 Proof of Proposition 2

The proof proceeds similarly to that of Proposition 1. In a price-quality separating equilibrium, the low-quality firm's price is still $P_L=P(q_o=H,q_u=L)=\frac{\beta+\gamma+c_o}{2}$. Given $b(P_L)=0$, the low-quality firm sets $q_o=H$, since the value to consumers more than outweighs the additional cost incurred. Considering the set $\{P|\pi(q_o = H, q_u = L, 0, P_L) = \pi(q_o = L, q_u = L, 1, P)\}$, we find that the boundary of the region within which the low-quality firm will not mimic the high-quality firm is given by $P_{pq}(X) = \frac{\alpha+\delta}{2} \pm \sqrt{\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}\left(\frac{\beta+\gamma-c_o}{2}\right)^2}$. Let $\overline{P}_{pq}(X)$ be the positive root of $P_{pq}(X)$, and note that $P_{pq}(X)$ only exists if $X < \overline{X}_{pq}$, where $\overline{X}_{pq} = \frac{(\beta-\alpha)(\alpha+\delta)^2}{(\delta-\gamma)(\beta+\gamma-c_o)^2} - 1$. Define X^m_{pq} by $P_{pq}\left(X^m_{pq}\right) = P^m_{pq}$. Again, the high-quality firm prices at $\overline{P}_{pq}(X)$ for $X < X^m_{pq}$, and at P^m_{po} for $X \geq X^m_{pq}$. These are the only prices satisfying the intuitive criterion, for exactly the same reasons as in Proposition 1.

6.4 Proof of Lemma 2

The profits from price-only and price-quality signaling are $\pi_{po} = M\left(\frac{B-P_{po}}{B-A}\right)(P_{po} - c_o - c_u)$ and $\pi_{pq} = M\left(\frac{\alpha+\delta-P_{pq}}{\delta-\gamma}\right)(P_{pq} - c_u)$, and the corresponding derivatives with respect to X are $\frac{\partial \pi_{po}}{\partial X} = \frac{M}{B-A}(B + c_o + c_u - 2P_{po})\frac{\partial P_{po}}{\partial X}$ and $\frac{\partial \pi_{pq}}{\partial X} = \frac{M}{\delta-\gamma}(\alpha + \delta + c_u - 2P_{pq})\frac{\partial P_{pq}}{\partial X}$. In order to have $\frac{\partial \pi_{po}}{\partial X} > \frac{\partial \pi_{pq}}{\partial X}$ for some X, the following inequality must be true:

$$(B - c_o)^2 - (\alpha + \delta)^2 > \frac{(1 + X)(B - A - \delta + \gamma)}{\beta - \alpha}(\beta + \gamma - c_o)^2. \tag{1}$$

Rearranging (1), it can be written as $X < \frac{\left[(B-c_o)^2-(\alpha+\delta)^2\right](\beta-\alpha)}{(B-A-\delta+\gamma)(\beta+\gamma-c_o)^2} - 1$ if $B - A - \delta + \gamma > 0$, and $X > \frac{\left[(B-c_o)^2-(\alpha+\delta)^2\right](\beta-\alpha)}{(B-A-\delta+\gamma)(\beta+\gamma-c_o)^2} - 1$ if $B - A - \delta + \gamma < 0$. Let $Y_1 = \frac{\left[(B-c_o)^2-(\alpha+\delta)^2\right](\beta-\alpha)}{(B-A-\delta+\gamma)(\beta+\gamma-c_o)^2} - 1$ and $Y_2 = \frac{\left[(B-c_o)^2-(\alpha+\delta)^2\right](\beta-\alpha)}{(B-A-\delta+\gamma)(\beta+\gamma-c_o)^2} - 1$. Then Y_2 is negative, and Y_1 may be positive or negative. Since $X \geq 0$ always, it is trivially true that $X > Y_2$ for every X. Also, if $X^* < Y_1$, then it must be true that $X < Y_1$ for every X less than X^*. Thus, whenever (1) is true for X^*, it is also true for $X < X^*$. This proves the lemma.

6.5 Proof of Lemma 3

The derivatives of prices with respect to X under each signaling regime are $\frac{\partial P_{po}}{\partial X} = -\frac{1}{2}\left[\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}Z\right]^{-1/2}\left[\frac{B-A}{\beta-\alpha}Z\right]$ and $\frac{\partial P_{pq}}{\partial X} = -\frac{1}{2}\left[\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{\beta-\alpha}Z\right]^{-1/2}\left[\frac{\delta-\gamma}{\beta-\alpha}Z\right]$, where $Z = \left(\frac{\beta+\gamma-c_o}{2}\right)^2$. Using these expressions along with the derivatives of $\frac{\partial \pi_{po}}{\partial X}$ and $\frac{\partial \pi_{pq}}{\partial X}$ from the preceding proof and substituting the expressions for prices, we have $\frac{\partial \pi_{po}}{\partial X} = \frac{-MZ}{\beta-\alpha}\left[\frac{c_u}{\sqrt{(B-c_o)^2 - \frac{(1+X)(B-A)}{\beta-\alpha}(\beta+\gamma-c_o)^2}} - 1\right]$ and $\frac{\partial \pi_{pq}}{\partial X} = \frac{-MZ}{\beta-\alpha}\left[\frac{c_u}{\sqrt{(\alpha+\delta)^2 - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}(\beta+\gamma-c_o)^2}} - 1\right]$. Next, let $B = \beta+\delta-\varepsilon$ and $B - A = \beta-\alpha+\delta-\gamma-2\varepsilon$ for some $\varepsilon > 0$. Establishing that $\frac{\partial \pi_{pq}}{\partial X} > \frac{\partial \pi_{po}}{\partial X}$ for ε close to zero proves that there can be no price-quality signaling if $B-A$ is sufficiently large. Then $\frac{\partial \pi_{pq}}{\partial X} > \frac{\partial \pi_{po}}{\partial X}$ if and only if $(\alpha+\delta)^2 - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}(\beta+\gamma-c_o)^2 > (\beta+\delta-\varepsilon-c_o)^2 - \frac{(1+X)(\beta-\alpha+\delta-\gamma-2\varepsilon)}{\beta-\alpha}(\beta+\gamma-c_o)^2$,which simplifies (approximately) to $(\beta+\delta-c_o)^2 - (\alpha+\delta)^2 < (1+X)(\beta+\gamma-c_o)^2$ for ε close to zero. Noting that $X \geq 0$ and using assumptions from Section 2, it is straightforward to establish this inequality. This proves the lemma.

6.6 Proof of Proposition 3

Consider the expressions for profit under each signaling regime: $\pi_{po} = \left(\frac{M}{B-A}\right)\cdot(B-P_{po})(P_{po}-c_o-c_u)$ and $\pi_{pq} = \left(\frac{M}{\delta-\gamma}\right)(\alpha+\delta-P_{pq})(P_{pq}-c_u)$. Substituting the expressions for prices and simplifying, these expressions are $\pi_{po} = \left(\frac{M}{B-A}\right)\cdot \left(\frac{B-c_o}{2} - \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}Z}\right)\left(\left[\frac{B+c_o}{2} + \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}Z}\right] - (c_o+c_u)\right) = \left(\frac{M}{B-A}\right)\left[\begin{array}{c}\frac{(1+X)(B-A)}{\beta-\alpha}\left(\frac{\beta+\gamma-c_o}{2}\right)^2 - \\ c_u\left(\frac{B-c_o}{2} - \sqrt{\frac{(B-c_o)^2}{4} - \frac{(1+X)(B-A)}{\beta-\alpha}Z}\right)\end{array}\right]$ and $\pi_{pq} = \left(\frac{M}{\delta-\gamma}\right)\left(\frac{\alpha+\delta}{2} - \sqrt{\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}Z}\right)\cdot \left(\left[\frac{\alpha+\delta}{2} + \sqrt{\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}Z}\right] - c_u\right) = \left(\frac{M}{\delta-\gamma}\right)\left[\begin{array}{c}\frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}\left(\frac{\beta+\gamma-c_o}{2}\right)^2 - \\ c_u\left(\frac{\alpha+\delta}{2} - \sqrt{\frac{(\alpha+\delta)^2}{4} - \frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}Z}\right)\end{array}\right]$, where $Z = \left(\frac{\beta+\gamma-c_o}{2}\right)^2$. In order for the high-quality firm to use price-quality signaling, it must be that this leads to greater profit: $\pi_{pq} > \pi_{po}$, which is true if and only if

$\left(\frac{B-A}{\delta-\gamma}\right)\left[\frac{\alpha+\delta}{2}-\sqrt{\frac{(\alpha+\delta)^2}{4}-\frac{(1+X)(\delta-\gamma)}{(\beta-\alpha)}Z}\right] < \frac{B-c_o}{2}-\sqrt{\frac{(B-c_o)^2}{4}-\frac{(1+X)(B-A)}{\beta-\alpha}Z}$. We cannot verify directly whether or when this expression is true. However, the expression becomes manageable under the following assumptions:

$$B = \alpha+\delta+\varepsilon_1 \tag{2}$$

$$B-A = \alpha-\beta+\delta-\gamma+2\varepsilon_1 \tag{3}$$

where $\varepsilon_1 > 0$ is small, and

$$\delta-\gamma = \beta-\alpha+\varepsilon_2 \tag{4}$$

where $\varepsilon_2 > 0$ is small. Note that (2) and (3) are true if $B-A$ is sufficiently small, and (4) is true if $\beta-\alpha$ is sufficiently large and $\delta-\gamma$ is sufficiently small (but the assumption that $\delta-\gamma > \beta-\alpha$ is maintained). Then the condition for price-quality signaling profit to be greater is $\left(\frac{\varepsilon_2+2\varepsilon_1}{\beta-\alpha+\varepsilon_2}\right)\left[\frac{\alpha+\delta}{2}-\sqrt{\frac{(\alpha+\delta)^2}{4}-\left[(1+X)\left(1+\frac{\varepsilon_2}{\beta-\alpha}\right)\right]Z}\right] < \frac{\alpha+\delta+\varepsilon_1-c_o}{2} - \sqrt{\frac{(\alpha+\delta+\varepsilon_1-c_o)^2}{4}-\frac{(1+X)(\varepsilon_2+2\varepsilon_1)}{\beta-\alpha}Z}$. Now assume $\varepsilon_1 = \frac{\beta-\alpha}{n_1}$ and $\varepsilon_2 = \frac{\beta-\alpha}{n_2}$, where n_1 and n_2 are large. Then the condition is $\left(\frac{3}{n_2+1}\right)\left[\frac{\alpha+\delta}{2}-\sqrt{\frac{(\alpha+\delta)^2}{4}-(1+X)\left(1+\frac{1}{n_2}\right)Z}\right] < \frac{\alpha+\delta+\frac{\beta-\alpha}{n_1}-c_o}{2} - \sqrt{\frac{\left(\alpha+\delta+\frac{\beta-\alpha}{n_1}-c_o\right)^2}{4}-(1+X)\left(\frac{1}{n_2}+\frac{2}{n_1}\right)Z}$, which is clearly true if we fix n_1 and choose n_2 sufficiently large (corresponding to $\delta-\gamma$ and $\beta-\alpha$ being close enough). Together with Lemma 2, this proves the proposition. Note also that raising c_o makes price-quality signaling relatively more attractive. However, for any value of c_o meeting the restrictions in Section 2, if the sufficient conditions are met, the high-quality firm prefers price-quality signaling.

6.7 Proof of Proposition 4

Consider a candidate equilibrium in which there is pooling at low observable quality. Each type of firm sets $q_o = L$ and price P, and consumers believe that the firm is high-quality with probability b. This would be the prior probability that a firm is high-quality. In order for this to be an equilibrium, consumers must believe that the low-quality firm is more likely than the high-quality firm to deviate to $q_o = H$. That is, if consumers observe a deviation, they would update their belief of the probability that the firm is high-quality to b', where $b' < b$. (If this is not true, both types of firm have incentive to deviate.) However, the high- and low-quality firms have essentially the same incentive to deviate to $q_o = H$. If beliefs are held fixed, the deviation profit would be greater for either type of firm. Therefore, according to the divinity criterion of Banks and Sobel (1987), a reasonable restriction on consumers' beliefs would be that the probability that the firm is high-quality is the same whether or not there is a deviation to $q_o = H$. Since both types of firm have incentive to deviate from the proposed equilibrium, the deviation itself conveys no information to consumers. Given this restriction on beliefs, either type of firm will in fact deviate to $q_o = H$, and the equilibrium candidate fails.

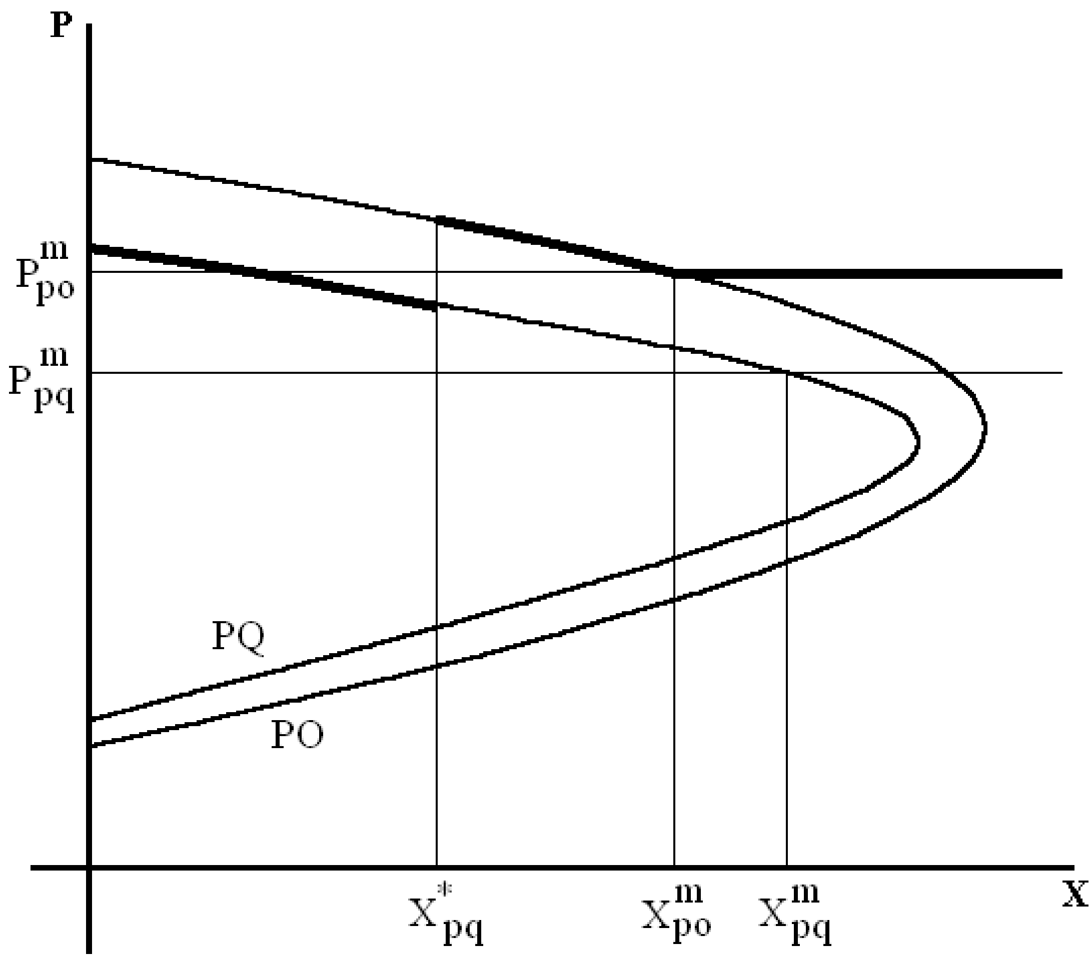

Figure 1: Price-quality signaling equilibrium

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