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QUALITY CHOICE, SIGNALLING, AND MORAL HAZARD

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In this paper it is argued that prices should not reveal the quality of the good to the consumers, when there is asymmetric information about quality between the firm and the consumers, and the firm can affect the quality of its product. Instead, prices should be completely uninformative, so that firms are able to make larger investments to improve the quality, and increase the expected utility of the consumers.

1. *Introduction*

The problem of how a firm could credibly signal the quality of its products to the consumers has received lots of attention during the last few years. Authors have examined how prices, advertising, or warranties, or some combination of these could be used to convince the consumers, that the quality of a good is actually high (Milgrom and Roberts 1986, Ramey 1987, Rogerson 1987). In these models the firm knows the quality, but the consumers know only the prior distribution over possible quality levels. Choosing the price, and/or advertising, and/or warranty levels properly, the firm can then reveal the quality of the good to the consumers, before they have purchased it. In these papers it is taken more or less granted that such a separating equilibrium is the most reasonable one in this case. (One exception being the paper by Laffont and Maskin (1987), who argue that a separating equilibrium might not be the »natural» solution to this problem.)

We will analyze a similar situation, but take the analysis one step further. We will assume that in order to be able to produce high quality goods, the firm must make some investments. Such investments could be interpreted as a R & D -effort to improve the quality of the good to be produced in the future. Four different models are analyzed. The models differ with respect to the time horizon (one or two periods) and with respect to observability conditions (investments are either observable or non observable to the consumers). A detailed analysis is given to the case in which the firm can only use price signals. The conclusion is what we shouldn't expect a separating equilibrium to be played. Instead, the price should reveal no information about the quality, because then the firm invests more in quality and the consumers are better off than in separating equilibria. In the concluding section it is argued that results would not change, if the firm could advertise after it has learnt the result of the R & D -efforts. On the contrary, it is argued that the firm should advertise at the R & D -stage, to make its investments common knowledge. In sections 2 and 3, equilibria in these models are analyzed. Section 4 concludes.

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2. *The model with no repeat business*

There is continuum of buyers having utility functions $t^*x - x^2/2 - px$ (Laffont and Maskin 1987), where t^* is the (expected) quality of the good, x the amount purchased, and p is the price. The monopolist therefore has the demand $x = t^* - p$ for its product. The quality of the product may take only two values, $T > t > 0$. Let us denote the expected quality by $t(q) = qT + (1-q)t$, where q is the probability of high quality. The unit cost of production is the same for both qualities, and may therefore be assumed to be equal to zero.

In this model the monopolist can affect the probability that the quality is high. If it wants that the quality is high with probability q, then it must pay c(q) units of money, $c(0) = 0 = c'(0)$, $c'(q), c''(q) > 0$, if $q > 0$, and $c'(1) = \infty$, If the monopolist is lucky, it can produce high quality goods. To simplify the analysis, we will assume that in such a case it *must* produce high quality goods. This is an innocent assumption, since producing high quality goods is no more expensive than producing low quality goods. In the complementary case it can produce only low quality goods.

The timing of the moves is the following: the firm chooses first the level of investment, c. This choice determines uniquely the probability of high quality, q. Having made this investment, the monopolist learns whether or not he is able to produce high quality goods. The monopolist chooses then the price, and the consumers decide how much to purchase. The expected profit for the firm at the investment stage is $\Pi(p, q' | q) = (t(q') - p)p - c(q)$, when the firm charges price p, chooses investment c(q), and the consumers believe that the probability of high quality is q'.

The consumers learn the actual quality of the good only after consuming it. The demand of the consumers depends on the price p and the »posterior» belief q'. The posterior q' in turn depends on the price, and the level of investment if this is observable. If the consumers can observe the investment, then they can also infer the »objective» probability of high quality, q. However, q' may not be equal to q, since q' also depends on the price. If the consumers cannot observe c at all, then there is also a »moral hazard» problem: the firm would like to choose low quality if the consumers would still believe that there is positive probability for the high quality. Both cases will be analyzed. The monopolist sells goods for one period or for two periods. In the latter case the quality of the good becomes common knowledge, if a positive amount was demanded in the first period. The analysis of this case is postponed to the next section.

Our solution concept is the perfect Bayesian equilibrium. In such an equilibrium, all players must maximize their expected utilities, given the current beliefs about the quality, and the strategies of their opponents. The beliefs are formed by using the Bayes' Rule, whenever possible, i.e., whenever the observed behavior of the firm is consistent with the equilibrium in question. Otherwise beliefs may be formed arbitrarily. If in an equilibrium the monopolist charges a different price (say, p(T)) when the quality is good than when the quality is bad (say, p(t)), then we have a *separating* equilibrium. If consumers expect one of these prices (as they will in this equilibrium), but they nevertheless observe a price p, $p \neq p(T)$, $p \neq p(t)$), then their beliefs about the quality may be formed arbitrarily. If the price does not reveal the quality, i.e., the monopolist charges the same price (say, p) independently of the quality, then the equilibrium is called *pooling*. If p is observed in this case, then the consumers cannot change their prior belief. If something else than p is observed, then again beliefs may be formed arbitrarily. Finally, we are looking for pure strategy equilibria only.

In any separating equilibrium, the firm with low quality must set $p(t) = \text{argmax}\{(t-p)p\} = t/2$. To see this, suppose $p(t) \neq t/2$ in a separating equilibrium. If the firm deviates to t/2, then it earns $(t(q) - t/2)\, t/2 \geq (t/2)^2 > (t - p(t))\, p(t)$ for any out of equilibrium beliefs $q \geq 0$, and for any $p(t) \neq t/2$, since $t(q) \geq t$. The firm earns then $(t/2)^2$. The price of the high quality must satisfy $(T - p(T))\, p(T) \leq (t/2)^2$, since otherwise the firm with low quality would imitate it. Strict inequality is ruled out, because then the firm with high quality would imitate the low quality firm. Therefore the firm earns $(t/2)^2$ independent of the quality of the good in any separating equilibrium, and $p(T) \in \{(T - (T^2 - t^2)^{0.5})/2, (T + (T^2 - t^2)^{0.5})/2\}$. But then the expected profit from choosing probability q for high quality is $(t/2)^2 - c(q) < (t/2)^2$ for any $q > 0$. This implies that the firm will produce low quality with probability one, whether the consumers observe its investment c(q) or not. We have the following result.

PROPOSITION 1. In the one period model with or without moral hazard, the quality is low with probability one, if prices should reveal the quality in equilibrium.

Proposition 1. tells us that no non trivial separating equilibria exist: if prices should reveal the quality, the quality will be low with probability one. Therefore all prices must signal that the quality is low.

Let's study pooling equilibria next. In a pooling equilibrium, the firm has to choose price p independently of the quality. If the investment in quality is not observable, and the consumers believe that the quality is high with probability q when p is observed, then the firm earns $(t(q)-p)p-c(q)$, if it indeed chooses p and q. If $q > 0$, then it will earn more by deviating to $q' = 0$ and setting price p. Therefore consumers cannot expect high quality with a positive probability in any pooling equilibrium, when there is moral hazard. The only equilibrium therefore is the one where $q = 0$, and $p = t/2$.

If the investment in quality is observable, then there are many pooling equilibria. Given q, the best pooling equilibrium for the firm is the one where $p^b = t(q)/2$, and the worst is the one where p^w is such that $(t(q)-p^w)p^w - c(q) = (t/2)^2$. Prices p^w and p^b can differ only if the optimal choice of q is greater than zero in the case p^b is chosen in equilibrium. This is the case when $(T-t)p^b = (T-t)t(q)/2 = c'(q)$, and $(T-t)^2/2 < c''(q)$, for some $q > 0$, that is, the function c must be »sufficiently» convex, which is assumed to be true. For any positive q, the price can be anything in the interval $[p^b-((p^b)^2-4(c(q)+(t/2)^2))^{0.5}/2,\ p^b+((p^b)^2-4(c(q)+(t/2)^2))^{0.5}/2]$, as long as the discriminant $(p^b)^2-4(c(q)+(t/2)^2)$ is non negative. Discriminant is non negative, if the best pooling equilibrium gives at least as high profits as the equilibrium with $q = 0$. Any deviations can be punished by the belief that the actual quality of the good is low. Notice how complex these equilibria may be. Consumer's off the equilibrium beliefs can depend on the investment chosen: even if the firm is allowed to charge p^b, the corresponding quality need not be the one which maximizes firms profits. In all these equilibria, there is a positive probability that the quality is high, in contrast to the situation where prices must credibly signal the quality. We have the following result.

PROPOSITION 2. If there is moral hazard, then the unique pooling equilibrium is the one in which the quality is low. If there is no moral hazard, then there are many pooling equilibria in which the quality is high with a positive probability.

If there is moral hazard, we have no problem in selecting the equilibrium: quality must be low and the price must be t/2. If there is no moral hazard problem, then there exists many equilibria. All equilibria are pooling, i.e., prices contain no information about quality. Intuitively the best pooling equilibrium for the firm seems to be the most reasonable outcome. In any other pooling equilibrium the consumers have the power to »punish» the firm by extremely pessimistic beliefs, if the firm deviates.

Let us briefly examine what would happen if the parties could sign contracts. Suppose that the quality is not verifiable to third parties, so that contracts cannot be conditioned on the actual quality. If the investment c is not observable, contracts cannot be conditioned on c either. In such a case the possibility for writing contracts does not change the situation at all: the firm would always make zero investments. Suppose then c is observable. This means that the firm can be forced to make the investment that maximizes total surplus, given that the individual rationality constraints are satisfied.

Denote the price and quantity by P and X if the firm announces that the quality is high, and denote the price and quantity by p and x if the firm announces that the quality is low (by the »Reveleation Principle», we don't have to consider more complex messages, see Myerson 1979). Maximize the total expected surplus $S(X, x, P, p, q) = q(TX-X^2/2) + (1-q)(tx-x^2/2)-c(q)$ with respect to X, x, and q, without taking the individual rationality and incentive constraints into account. This gives us $X^* = T$, $x^* = t$, and $T^2/2 - t^2/2 = c'(q^*)$ (y^* means the optimal value of y, for all choice variables y). These values are the first best choices of X, x and q. The firm must be given incentives to correctly announce the actual quality of the good, which implies that $P^*T = p^*t$. Now the maximized surplus is strictly positive, i.e., $q^*T^2/2 + (1-q^*) t^2/2 > c(q^*)$, since setting $q = 0$ would make the surplus strictly positive. Therefore there is a real number A so that $q^*T^2/2 + (1-q^*) t^2/2 - A > 0$, and $A - c(q^*) > 0$. Setting $P^* = A/T$ and $p^* = A/t$ quarantees that the individual rationality and incentive constraints are satisfied. We have constructed a contract which implements the first best. The contract can be interpreted in the following way: the consumers pay first a fixed fee A to the firm. The firm then makes the investment $c(q^*)$, and announces the consumers if the quality is high or low. The consumers are then allowed to purchase the good at the price which equals marginal cost (which is zero in our example). Since the investment is observable, the firm can be forced to invest $c(q^*)$.

3. *The model with repeat business*

In this model, the firm is selling its good during two periods. Otherwise the model is the same as in the last section. If there is positive demand in the first period, then the quality becomes common knowledge in the last period.

Pricing behavior in any separating equilibrium must be similar in the first period than in the last section, otherwise either low quality firm would like to imitate the high quality firm or vice versa. First period profits are therefore $(t/2)^2$, independently of the quality. Since there is positive demand in the first period, the low quality firm gets $(t/2)^2$ in the second period, and the high quality firm gets $(T/2)^2$. The expected profit in a separating equilibrium with a given q is therefore $\Pi(q) = (t/2)^2 + q(T/2)^2 + (1-q)(t/2)^2 - c(q)$. If there is moral hazard, the equilibrium cannot be conditioned on q, which implies that in a separating equilibrium q satisfies $(T/2)^2 - (t/2)^2 = c'(q)$, or $q = 0$. Low quality ($q = 0$) is chosen, iff $\Pi(q) < 2(t/2)^2$, iff $(T/2)^2 - (t/2)^2 < c(q)/q$. Since c is convex, this will never be the case. Let us denote by q^* the unique solution of $(T/2)^2 - (t/2)^2 = c'(q)$.

It the investment is observable (no moral hazard), then in principle the equilibrium could be conditioned on q so that q^* would not necessarily be the equilibrium choice. Suppose $q \neq q^*$ should be the equilibrium choice. Then if the firm deviates to q^*, the worst that can happen is that the consumers believe that the quality is low, even when the firm tries to signal that it is high. But then the firm with high quality would imitate the low quality firm by setting $p = t/2$, getting first period profits $(t/2)^2$. The second period profits must then be $(T/2)^2$ for the high quality firm. This implies that q^* must be chosen also when investments are observable. The equilibrium outcome is unique again.

PROPOSITION 4. In any separating equilibrium, with or without moral hazard, the probability of high quality is chosen so that $(T/2)^2 - (t/2)^2 = c'(q^*)$, and the first period profits are $(t/2)^2$ independent of quality.

If a pooling equilibrium is to be played and the investment in quality is not observable, then what happens in the first period cannot affect the choice of q, since the consumers cannot condition their beliefs on the *actual* q. Therefore the optimal q will be either zero, or the same q^* as above: $(T/2)^2 - (t/2)^2 = c'(q^*)$. Denote the first period profits by $\pi(p, q)$, when consumers expect q having observed price p. In equilibrium, $q = q^*$ must be expected. Then in any pooling equilibrium p must be such that $\pi(p, q^*) \geq (t/2)^2$, since $\pi(t/2, q) \geq (t/2)^2$ for any q. Since $\pi(p, q^*) \geq (t/2)^2$, the optimal q must be again q^* and not zero. On the other hand, any p which satisfies this relationship will do, since deviations can always be punished by the belief $q = 0$, which is the worst that can happen to the firm. In the best equilibrium from the firms point of view $p = (q^*T + (1-q^*)t)/2$. In any pooling equilibrium the profits are higher than in the separating equilibria.

If the investment is observable, the probability of high quality may no more be q^*. However, if the equilibrium involves q' and first period price p', then $\pi(p', q') \geq (t/2)^2$ must hold for the same reason as above. The minimum utility the firm can get in any equilibrium is equal to $(t/2)^2 + q^*(T/2)^2 + (1-q^*)(t/2)^2 - c(q^*)$, since if the worst alternative in the first period is expected, the firm may freely choose q^*, which is optimal in this case. This implies once more the $q = 0$ is impossible (although q could be smaller or greater than q^*) in equilibrium. The best pooling equilibrium from the viewpoint of the firm involves $p^b = (q'T + (1-q')t)/2$, where q' satisfies $(T-t)(q'T + (1-q')t)/2 + (T/2)^2 - (t/2)^2 = c'(q')$. Notice that $q' > q^*$ always. Also the profits must now be higher than in the best pooling equilibrium when there is moral hazard.

PROPOSITION 5. If there is moral hazard, then the quality must be q^* so that $(T/2)^2 - (t/2)^2 = c'(q^*)$, in any pooling equilibrium. Any price p so that the first period profit satisfies $\pi(p, q^*) \geq (t/2)^2$ can be an equilibrium price. If there is no moral hazard, then the quality is not necessarily q^*. Any first period price p' and quality q' can belong to some pooling equilibrium, if $\pi(p', q') \geq (t/2)^2$, and if the utility in equilibrium is not smaller than in the separating equilibrium.

Since there exist separating equilibria, the equilibrium selection problem looks much more challenging now than in the previous section. However, separating equilibria do not seem to be reasonable outcomes. To see this, note that since the first period profit is the same independently of the quality, the high quality firm does not loose if it imitates the low quality firm, and vice versa. If the high quality firm thinks that the consumer might actually *not* believe that the quality is high with probability one (but only with a »very high probability»), when p(T) is observed, then it should charge $p(t) = t/2$ instead of p(T). This is so because $(t(q)-p(T))\,p(T) < (t/2)^2 < (t(q)-p(t))\,p(t)$, for all $q \in (0,1)$. The price t/2 is a safe choice: it quarantees the firm *at least* $(t/2)^2$ units of profits in the first period, whereas p(T) is a risky choice: the profit can be *at most* $(t/2)^2$. In this sence the separating equilibria are not »stable».

In fact, a bit more elaborate argument than the one above shows that separating equilibria are not »trembling hand perfect» (see van Damme 1987). One could show that the pooling equilibrium that is best for the firm, satisfies this refinement concept. Unfortunately, this is not the only trembling hand perfect equilibrium. However, the best pooling equilibrium for the firm seems intuitively to be the most reasonable solution, since there are lots of consumers, and each individual consumer has no market power. Therefore any individual consumer should behave like a passive price taker. Since no binding commitments are allowed among the consumers, it is not unreasonable to assume that the whole group of consumers behaves like a passive price taker. If we make this assumption, we are able to make some welfare analysis.

If the moral hazard problem is present, then the firm invests $c(q^*)$ dollars in quality, where q^* satisfies $(T/2)^2 - (t/2)^2 = c'(q^*)$. If there is no moral hazard, then the investment is $c(q')$, where q' satisfies $(T-t)\,t(q')/2 + (T/2)^2 - (t/2)^2 = c'(q')$. Clearly, $q' > q^*$. Since the expected utility for the consumers is $(t(q))^2/8$, when the firm is allowed to choose the price, it is seen that moral hazard causes underinvestment in quality. But even when there is no moral hazard, the firm invests less in quality than would be socially optimal. Given that the firm is allowed to choose the price freely, the socially optimal level of investment would be $c(q^s)$, where q^s satisfies $3(T-t)\,t(q^s)/4 + (T/2)^2 - (t/2)^2 = c'(q^s)$. Clearly, $q^s > q' > q^*$, so that there is always underinvestment in quality, and moral hazard makes this problem even worse.

5. *Conclusions*

We have examined the pricing behavior of a firm in a situation in which it can affect the quality of its product, and the resulting quality is initially known by the firm only. In the one period model there exists no separating equilibria. Therefore prices cannot contain information about quality in any equilibrium. In the two-period model separating equilibria exist, but they are not reasonable equilibria in this case. Again, prices must be totally uninformative in all resonable equilibria.

We observed also that the firm invests too little in quality, and that this problem becomes even worse when there is moral hazard. If the firm could somehow credibly signal the level it plans to invest in quality, then this would increase the welfare of both parties, provided the cost of such a signalling is not too large. The firm should try to make it common knowledge that it is spending lots of money to improve the quality of its product in the future, by an advertising campaign at the R

& D -stage, for example. This kind of advertising is different than the one Milgrom and Roberts (1986) consider. In their model, the firm advertises after it has learnt the quality. By doing so the firm tells the consumers that the quality must be high, otherwise it would make huge losses. In our model, such »public burning of money» would not help, since the high quality firm can not make larger profits than the low quality firm in the first period, and therefore investment in quality would be the same as in the separating equilibria we have examined.

We dit not consider the possibility that the firm could offer warranties that the quality is high. If warranties are allowed, then it is easy to see that the type selling high quality goods could set the price equal to its complete information monopoly price, and offer so large warranties that the low quality type could not imitate it. Price and warranty would then reveal the quality without error, and the firm would invest in quality as much as in the complete information case. Warranties are feasible only if the quality of the good is verifiable to third parties, too, otherwise the consumers cannot rationally expect that warranties are paid in the case the good turns out to be bad.

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