Investment in quality under asymmetric information with endogenously informed consumers

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Received 11 August 1999; accepted 31 January 2000

Abstract

When sellers are privately informed about quality, signaling models can successfully explain an equilibrium correlation between prices and \textit{exogenous} quality but do not account for incentives to \textit{invest} in quality improvement. This paper shows that sellers may be motivated to invest in quality if consumers, though initially uninformed, may acquire costly information before buying. The equilibrium has the attractive feature that incentives to invest are greater the less costly it is for consumers to become informed.

Keywords: Product quality; Asymmetric information; Signalling

\textit{JEL classification:} L0

1. Introduction

The folklore that ‘you get what you pay for’ meets with a well known problem. If high prices signal high quality, what is to prevent unscrupulous, low quality sellers from charging high prices as well? Several papers have shown that when quality is \textit{exogenous}, a high quality seller, because of its higher costs, can credibly signal with a price sufficiently above the full information equilibrium level that would be unprofitable for a low cost, low quality seller to mimic (cf. Tirole, 1988, chap. 2, and references therein).

However, this argument cannot motivate the \textit{choice} to provide high quality (Tirole, 1988, pp. 106–107). Investment in quality is unprofitable because, in the separating equilibrium, higher quality

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commands a lower price–cost margin. The motivation to provide high quality must then rely on repeated play considerations (e.g., Klein and Lafler, 1981; Shapiro, 1982). The purpose of this paper is to show that the signaling approach can account for investment in quality if consumers are able to acquire costly information before buying, through independent research, the study of consumer literature such as Consumer Reports, and so on. In particular, the equilibrium we derive has the nice feature that the incentive to invest is greater, the less costly it is for buyers to become informed.

The paper most closely related to this one is Bagwell and Riordan (1991). They show that when a proportion of consumers is exogenously informed, the high quality seller signals by initially charging high prices which decline over time as the number of informed consumers increases. The main difference between this paper and theirs is that Bagwell and Riordan consider exogenous quality while this paper is concerned with incentives to invest in quality.

2. A quality investment game

A market consists of a monopoly seller and identical buyers, whose number is normalized to one. Product quality may be either low or high. The ability to produce high quality requires an R&D investment of \( I > 0 \), which is only successful with probability \( \beta < 1 \). If investment is unsuccessful, only low quality can be produced. A high (low) quality seller is able to supply any quantity at a constant marginal cost of \( c_H \) (\( c_L \)). Each buyer demands a single, indivisible unit at the most. The value of a low and high quality unit to a buyer is \( V_L \) and \( V_H \) respectively, which are the monopoly prices for low and high quality if consumers are perfectly and costlessly informed. We shall assume that investment is efficient; that is,

**Assumption 1.** \( \beta (V_H - V_L) > I \).

If the seller invests, it is privately informed about the outcome of investment. Buyers observe only if the seller invests, but not whether investment was successful. More specifically, assume the following sequence of events. At the first stage, the quality investment stage, the seller decides whether or not to invest, and, if it does, privately learns whether it is low or high quality. At the second stage, the pricing stage, it sets a price. Buyers observe the price, update beliefs about quality and decide whether or not to buy at that price.

The seller’s objective is to maximize its expected profit and a buyer’s objective is to maximize its expected surplus, \( V_i - p, i = L, H \), where \( p \) is the price. We look for a Bayesian Nash equilibrium. This specifies, for the seller, whether to invest, and a price for each quality realization, and, for buyers, at what prices to buy. An equilibrium in which the seller invests in quality will be referred to as an ‘investment equilibrium’.

**Proposition 1.** If buyers are uninformed about quality, an investment equilibrium does not exist.

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1In this paper quality refers to how well the product does its job, its durability and so on. In an interesting recent paper, Daughety and Reinganum (1995) consider a different dimension of quality, namely product safety. They show that prices may effectively signal product safety when consumers who suffer injury from using the product may litigate for damages.
Proof. Suppose there is a pure strategy investment equilibrium and consider its pricing subgame. Let \( p_L \) and \( p_H \) denote the equilibrium prices of low and high quality, respectively, and let \( q_L \) and \( q_H \) be the quantity demanded at prices \( p_L \) and \( p_H \) respectively. Suppose the equilibrium of the pricing subgame is separating, i.e., \( p_L \neq p_H \). Then the low quality and high quality producer’s profits are \((p_L - c_L)q_L\) and \((p_H - c_H)q_H\) respectively. \( p_L \) must be optimal for the low quality seller and \( p_H \) must be optimal for the high quality seller. That is:

(i) \((p_L - c_L)q_L \geq (p_H - c_L)q_H\)

(ii) \((p_H - c_H)q_H \geq (p_L - c_H)q_L\)

Since \( c_H \geq c_L \), (i) implies that the operating profit of a low quality producer is at least as great as that of a high quality producer. Since the ability to produce high quality requires costly investment, investment can not be optimal. Thus the equilibrium of the pricing subgame must be pooled, i.e., \( p_L = p_H \). In that case, buyers cannot distinguish between a low and high quality seller, implying that \( q_L = q_H \). Thus, the low quality type’s operating profit is again at least as great as that of the high quality type, so that investment cannot be optimal. Analogous arguments eliminate mixed strategy investment equilibria. □

The next section shows that this result is overturned if consumers can invest in information before buying.

3. Endogenously informed buyers

We now expand the model by enabling consumers to become perfectly informed about quality, from a reliable external source or through private research, at a cost of \( s > 0 \). The sequence of events is now as follows. After the seller makes its investment decision, learns its quality and sets its price, consumers choose between the following options: to become informed before buying, to buy without becoming informed, or to exit the market without buying or becoming informed. To economize on notation (without changing the analysis in any important way), let \( c_L = c_H = 0 \).

The following proposition is our main result.

Proposition 2. There exists \( s^* > 0 \) such that corresponding to each \( s < s^* \) there is an investment equilibrium in which the seller invests in quality if \( I < I(s) \), where \( I(s) \) is decreasing in \( s \) and \( I(s) \rightarrow \beta(V_H - V_L) \) as \( s \rightarrow 0 \).

The proposition is proved with the following lemma.

Lemma 1. Consider a (post investment) pricing subgame in which the buyers’ prior belief (before observing the price) is that quality is high with probability \( \beta \) and low with probability \( 1 - \beta \). There exists a partial pooling equilibrium for this subgame in which the price of high quality is \( \hat{p}(s) > V_L \), while the low quality seller randomizes between \( V_L \) and \( \hat{p}(s) \). As \( s \) decreases, \( \hat{p}(s) \) and the probability with which the price of low quality is \( V_L \) increase. And as \( s \rightarrow 0 \), \( \hat{p}(s) \rightarrow V_H \) and the probability with which the price of low quality is \( V_L \) → 1.
Proof of Lemma 1. The proof is by construction. Let $\Delta \equiv V_H - V_L$ and $s^* \equiv \beta(1 - \beta)\Delta$. Let

$$
\xi(s) = \begin{cases} 
(1 + \left(\sqrt{1 - \frac{4s}{\Delta}}\right)/2 & \text{if } s \leq s^* \\
\beta & \text{if } s > s^* 
\end{cases}
$$

and let

$$
\hat{p}(s) = \xi(s)V_H + (1 - \xi(s))V_L.
$$

Let strategies be as follows:

**The high quality seller:** Charge $\hat{p}(s)$ with probability 1.

**The low quality seller:** If $s < s^*$, charge $V_L$ with probability $\gamma(s) = 1 - \beta(1 - \xi(s))/(\xi(s)(1 - \beta))$ and $\hat{p}(s)$ with probability $1 - \gamma(s)$. If $s > s^*$, charge $\hat{p}(s)$ with probability 1.

**Consumers:** If the price is $p \leq V_L$, buy without becoming informed. If $\hat{p}(s) > p > V_L$, or if $p > \hat{p}(s)$, exit the market. If $p = \hat{p}(s)$ and $s < s^*$, become informed with probability $\alpha \equiv 1 - V_L/\hat{p}(s)$ (in which case buy only if quality is high) and buy without becoming informed with probability $1 - \alpha$. If $p = \hat{p}(s)$ and $s \geq s^*$, buy without becoming informed.

This strategy profile constitutes an equilibrium if consumers maximize expected surplus given the seller’s strategy and the seller maximizes expected profit given the consumers’ strategy. These two requirements are examined in turn.

**Optimality of Buyers’ Strategy:** Given the above sellers’ strategy, by Bayes’ rule, the consumer’s posterior probability that quality is high when the price is $\hat{p}(s)$ is $\beta/[\beta + (1 - \beta)(1 - \gamma(s))]$ if $s < s^*$ and $\beta$ if $s > s^*$. Substituting for $\gamma(s)$ in the preceding expression gives the posterior probability as $\xi(s)$. Thus, when the price is $\hat{p}(s)$, her expected utility from becoming informed is $-s + \xi(s)(V_H - \hat{p}(s))$ and her expected utility from buying without becoming informed is $\xi(s)(V_H - \hat{p}(s)) + (1 - \xi(s))(V_L - \hat{p}(s))$. Substituting for $\hat{p}(s)$ and $\xi(s)$ in the preceding expressions reveals that if $s < s^*$, $-s + \xi(V_H - \hat{p}(s)) = \xi(V_H - p_H) + (1 - \xi)(V_L - \hat{p}(s)) = 0$. The utility from leaving the market without buying is zero. Since all three options yield identical utility, the buyers’ strategy to randomize between becoming informed and buying without becoming informed is optimal when the price is $\hat{p}(s)$. Similarly, if $s > s^*$, the utility from becoming informed is negative while the utility from buying without becoming informed is zero so that in this case it is optimal to buy without becoming informed if the price is $\hat{p}(s)$.

Let the buyers’ (out of equilibrium) belief that quality is high when the price is $p \neq \hat{p}(s)$ be given by:

$$
b(p) = \begin{cases} 
0 & \text{if } p < \hat{p}(s) \\
\xi(s) & \text{if } p > \hat{p}(s) 
\end{cases}
$$

Then in all cases it is optimal to exit the market without buying if $V_L < p < \hat{p}(s)$ or if $p > \hat{p}(s)$. This establishes optimality of the consumers’ strategy.

**Remark 1.** Note that the above consumers’ (out of equilibrium) beliefs are ‘natural’ in that they associate higher prices with non-decreasing probability of high quality. We elaborate on this further in Section 4.
Optimality of Seller’s Strategy: Since all buyers reject \( p > \hat{p}(s) \) and \( V_L < p < \hat{p}(s) \), the only prices to consider are \( \hat{p}(s) \) or \( V_L \). Since both informed and uninformed buyers accept \( \hat{p}(s) \) if quality is high, the high quality seller’s profit from \( \hat{p}(s) \) is \( \hat{p}(s) > V_L \). Thus \( \hat{p}(s) \) is optimal for a high quality seller. If \( s < s^* \), a low quality seller’s profit from \( \hat{p}(s) \) is \( (1 - \alpha(s))\hat{p}(s) = V_L \). If \( s > s^* \), its profit from \( \hat{p}(s) \) is \( \hat{p}(s) \), since no buyers are informed. It is therefore optimal for the low quality seller to randomize between \( V_L \) and \( \hat{p}(s) \) if \( s < s^* \) and to deterministically charge \( \hat{p}(s) \) if \( s > s^* \).

The preceding has established that the strategy profile constitutes an equilibrium. It is immediately verifiable that \( \hat{p}(s) \), which is also the high quality seller’s profit, is decreasing in \( s \) and goes to \( V_L \) as \( s \to 0 \) and that, for \( s < s^* \), \( \gamma(s) \) is increasing in \( s \), and goes to 1 as \( s \to 0 \). 

In the equilibrium described by the preceding lemma, consumers who are charged the high price, \( \hat{p}(s) \), randomize between becoming informed — and thus buying only if quality is high — and between buying without becoming informed. This determines the trade-off between \( V_L \) and \( \hat{p}(s) \) for the low quality seller. While \( V_L \) is accepted by all buyers, only the uninformed pay the high price for the low quality product. In equilibrium, \( \hat{p}(s) \) serves as a noisy signal of quality; although it may be charged by either type of firm, it is more likely to originate from the high than the low quality seller. The equilibrium has the nice property that this price becomes more informative the cheaper it is for buyers to become informed and becomes perfectly revealing in the limit, as \( s \) goes to zero.

Lemma 1 implies that high quality seller’s operating profit exceeds that of the low quality seller, that the difference between them increases as \( s \) decreases and approaches \( V_L - V_I \) in the limit. This profit difference provides the incentive to invest in quality, as is argued in the proof below.

Proof of Proposition 2. Suppose the equilibrium described by lemma 1 obtains for the pricing subgame in which buyers believe that quality is high with probability \( \beta \). Let

\[
I(s) = \begin{cases} \beta(\hat{p}(s) - V_L) & \text{if } s < s^* \\ 0 & \text{if } s \geq s^* \end{cases}
\]

(where \( s^* \) is defined in the proof of Lemma 1), and let the seller’s strategy be: invest if and only if \( I < I(s) \). When the seller invests, the consumers’ prior (before observing the price) that quality is high must be \( \beta \) (recall that buyers observe whether or not the seller invests) so that the lemma applies. Therefore, the operating profit (gross of the investment, \( I \)) of the high quality seller is \( \hat{p}(s) \) while the expected operating profit of the low quality seller is \( V_I \). Thus it is optimal to invest if \( I < I(s) \).

4. Discussion

In addition to the investment equilibrium, there also exists an equilibrium in which there is never any investment (no matter how small is \( s \)). In this equilibrium, investment is unprofitable because consumers believe that unless the price is sufficiently low (sufficiently near \( V_L \), quality is low with sufficiently high probability. This makes the equilibrium price differential between low and high quality too small to cover investment costs. However, such beliefs seem contrived and artificial in contrast to the investment equilibrium which is supported by beliefs that associate higher prices with a non decreasing probability of high quality (cf. ‘Remark 1’ in the proof of Lemma 1). Therefore the investment equilibrium seems like the more natural equilibrium.
5. Conclusion

It has been shown that equilibrium incentives to invest in quality improvement exist if consumers are able to invest in information, before buying. The equilibrium has the intuitive property that the incentive to invest is greater the less costly it is for buyers to become informed. In this model, the consumers' information option limits the low quality seller’s incentive to mimic the high quality price, but does not eliminate it altogether (except in the limit). Thus prices and quality are imperfectly correlated and some consumers are fooled in equilibrium, a feature which I suspect might correspond with the reader's experience.

References