E C O N O M I C S   B U L L E T I N

Quality over−provision of information goods

Xiaopeng Xu
University of California−Berkeley

Abstract

This paper studies a producer's quality choice of an information good. The marginal cost of quality provision for the good is decreasing. The buyer does not observe the actual quality but can learn a signal which is the sum of quality and a noise. It shows that the producer has an incentive to over−supply quality. Moreover, and interestly, all types of producer may over−supply quality.

I thank an anonymous referee for very helpful comments.
Citation: Xu, Xiaopeng, (2002) "Quality over−provision of information goods." *Economics Bulletin,* Vol. 12, No. 5 pp. 1−9
Submitted: February 21, 2002. **Accepted:** March 8, 2002.
URL: http://www.economicsbulletin.com/2002/volume12/EB−02L10001A.pdf

1. Introduction

The U.S. economy is increasingly dominated by knowledge and information goods, such as semiconductor products, and increasing returns to quality production are the everyday phenomenon. As Jorgenson (2001) puts, "A mantra of the "new economy" -- *faster*, *better*, *cheaper* -- captures the speed of technological change and product improvement in semiconductors and the precipitous and continuing fall in semiconductor prices."

There are two distinct features of information goods. The first is that marginal cost of quality provision for a unit of information good may be decreasing. Semiconductor manufacture is such a case. It is an extraordinary dynamic industry, where technological change, as a result of R&D and learning by doing, dramatically reduced the real price of a unit of computing capacity. Between 1974 and 1996, prices of memory chips decreased by a factor of 27,270 times or 40.9 percent per year. And between 1985 and 1996, prices of logic chips decreased by a factor of 1,938 or 54.1 percent per year. Semiconductor price declines closely parallel the growth of chip capacity, setting semiconductors apart from other products (Jorgenson, 2001). It is indicative that the marginal cost of quality provision for a given unit of computing capacity has been decreasing (Moore, 1965, and Grimm, 1998).

The second feature is that information goods are knowledge embodied. As a result, a buyer can learn quality of an information good only over time. Differently put, at the time of purchase, the buyer can learn the actual quality of information goods only with a noise (see also von Ungern-Sternberg and von Weizsäcker, 1985). For example, the buyer may identify the number of transistors contained in a memory chip with quality. But the actual quality depends both on the number of transistors and on other factors, captured by a random term not observed by the buyer.

This paper analyzes the quality choice of a producer who produces and sells an information good to a one-time buyer. Clearly, a producer who sells an information good to a one-time purchaser who has absolutely no knowledge about or observe no signal of quality will have strong incentives to cut quality (so long as quality is costly to provide) to the lowest possible level, simply because, given the market price, provision of quality above the lowest level is not optimal for the producer. Realizing this, the consumer will pay a price corresponding to the lowest level of quality.

Then, a question naturally arises: Will the producer unambiguously under-supply quality in the case where the buyer observes a noisy signal of quality as in the case in which the consumer has no knowledge of quality?

I explore this question by assuming a simple signal technology under which the signal observed by the buyer is the sum of the actual quality and a noisy term (the state of nature). I show that, except for the best type, all types of producer, identified with states of nature, will over-supply quality. Moreover, and interestingly, *all* types of producer may over-provide quality. In this case, the price set by the producer is the same in all states of nature, independent of the actual quality of the good. In other words, the producer does not necessarily charge higher prices for better products. Differently put, quality-adjusted prices of information goods may decline. This result is consistent with the empirical findings of constant quality price indexes in computer, communication, and software industries (Jorgenson, 2001).

In my model, there are a buyer with non-contractible quality needs and a large pool of potential producers (and hence the buyer has all the bargaining power). Several papers make a similar assumption. Non-contractibility of an important aspect of product is explicitly assumed in Lewis and Sappington (1988), MacLeod and Malcomson (1988), Hart and Moore (1990), Bac (2000), and Chen (2000).

The rest of the paper is structured as follows. In Section 2, I set up and analyze the model, and Section 3 offers some concluding remarks.

2. The model

A buyer and a producer sign a contract for the delivery of one unit of knowledge or information good. For ease of presentation, let the producer be He and the buyer be She. The buyer is the principal and the producer the agent. The contract specifies a price, p, paid to the producer by the buyer. In principle, the contract can be based on all observable and verifiable information. The producer will obtain a normalized payoff of zero if no deal is reached. This represents the best alternative payoff to the producer.

For simplicity, assume that both the producer and the buyer are risk-neutral. Given the quality level, q, and the price level, p, the buyer's payoff function is

$$U(q, p) = R(q) - p, \tag{1}$$

where it is assumed that $R'(q) > 0$ and $R''(q) < 0$, for all q. Higher quality yields higher benefit to the consumer, but at a decreasing rate.

The producer's payoff function is

$$V(q, p) = p - C(q), \tag{2}$$

where it is assumed that $C'(q) > 0$, for all q. In this paper, I consider an information good whose marginal cost of quality provision is decreasing, $C''(q) < 0$, for all q.

The quality of the information good is not observable by the buyer before purchase. However, the buyer is able to observe a signal that is the sum of quality and an error term (the state of nature). Denote the signal by s, and the state of nature by $\theta \in [\underline{q}, \bar{q}]$. The signal function is

$$s = q + \theta. \tag{3}$$

Given θ, a higher quality level results into a higher signal level on a one-to-one basis.

The producer knows the realization of the state, $\theta \in [\underline{q}, \bar{q}]$, before contracting, while the buyer knows about only the distribution of θ. The cumulative distribution function is $F(\theta)$, with the density function $f(\theta) = F'(\theta) > 0$ almost everywhere (a.e.).

Before proceeding, let us analyze two benchmark cases. In the first, s = q, i.e., quality is observable. In the second, $s = \{\phi\}$, the empty set, i.e., the consumer has absolutely no knowledge about quality. If q is observable, the first-best outcome is achievable. The buyer will demand a quality level q* which maximizes the total surplus, R(q) – C(q), and pays, $p^* = C(q^*)$, to the producer. The first-best quality level, q^*, is given by the first-order condition

$$R'(q^*) = C'(q^*). \tag{4}$$

It is assumed that the second-order condition is also satisfied. Thus, the first-best quality level q^* is unique.

In the second case, no signal of quality is available to the buyer. The producer will provide a quality of 0, and the buyer will pay him $p = C(0)$. Note that it is implicitly assumed here that 0 is the minimum possible level of quality. The minimum level may be a legal standard or the level at which consumers can supply convincing evidence of under- provision of quality.

Let us turn now to the main focus of the paper and analyze the producer's quality choice when the consumer has access to a linear signal technology. The price paid by the consumer to the producer can be based on the observable signal. But this is not approach we are going to take here. Rather, we appeal to the direct mechanism. By the revelation principle, there is no loss of generality in limiting the contract to the direct mechanism. Under the direct mechanism, the producer (truthfully) reports his type (identified with the state of nature), and the buyer requires a realization of a signal level and makes a payment to the producer, both based on the producer’s report of the state. Thus, we can think of the buyer as specifying a menu of signal and price pair, $(s(\theta), p(\theta))$, contingent on the producer’s truthful report of the state. Formally, the buyer chooses $(s(\theta), p(\theta))$ to

$$\text{Maximize } \mathbf{E}[R(s(\theta) - \theta) - p(\theta)] \tag{5}$$

subject to

$$V(\theta, \theta) \geq 0, \qquad \text{(IR)}$$

$$V(\theta, \theta) \geq V(\theta, \hat{q}), \text{ for all } \theta, \hat{q} \in [\underline{q}, \bar{q}], \qquad \text{(IC)}$$

where $\mathbf{E}$ is the expectation operator, taken over θ, and $V(\theta, \hat{q}) = p(\hat{q}) - C(s(\hat{q}) - \theta)$ is the producer’s payoff when he is of type θ but reports type $\hat{q}$. In the buyer's maximization program (5), (IR) are the producer's participation constraints, ensuring that the producer gets at least his reservation payoff in each state, and (IC) is the producer's incentive compatibility constraints, ensuring that the producer will truthfully report his type.

I first characterize the producer's incentive compatibility constraints. For an arbitrary signal-price pair, (s, p), the producer’s payoff in state θ is $V(s, p, \theta) = p - C(s - \theta)$. Clearly,

$$\partial V/\partial\theta = - C'(q)Q_\theta = C'(q) > 0, \tag{6}$$

and $$\partial^2 V/\partial\theta\partial s = - C'(q)Q_{\theta S} - C''(q)Q_\theta Q_S = C''(q) < 0. \tag{7}$$

(7) indicates that the single-crossing condition is satisfied (Guesnerie and Laffont,1984, and Fudenberg and Tirole, chapter 7).

A signal schedule, $s(\theta)$, which depicts signal as a function of state, is referred to be implementable, if it, together with the corresponding price schedule, $p(\theta)$, satisfies the (IR) and (IC) constraints in (5). Following the analysis of Guesnerie and Laffont (1984) or Fudenberg and Tirole (1991, chapter 7), we immediately have the following result.

Lemma 1. The necessary and sufficient conditions for $s(\theta)$ to be implementable are: i) $v'(\theta) = C'(s(\theta) - \theta)$, where $v(\theta) = V(\theta, \theta)$, and ii) $ds/d\theta \leq 0$.

(i) indicates that a higher θ is a better state for the producer, as it gives him a higher payoff. In equilibrium, $v(q) = 0$, and $v(\theta) > 0$, for all $\theta > q$. The price schedule is given by $p(\theta) = C(s(\theta) - \theta) + v(\theta)$. Making use of (i), one can easily show that $p'(\theta) = C'(s(\theta) - \theta)s'(\theta)$. When $s'(\theta) < 0$, $p'(\theta) < 0$; and when $s'(\theta) = 0$, $p'(\theta) = 0$. Note that $q(\theta) = s(\theta) - \theta$. Hence, $q'(\theta) = s'(\theta) - 1 < 0$. Therefore, with the simple trick of variable change, one can express p as a function of q and further show that, if $s'(\theta) < 0$, $p'(q) > 0$, and if $s'(\theta) = 0$, $p'(q) = 0$. In the latter case, the price charged by the producer is independent of the actual quality of the good.

Due to his possession of private information, the producer receives information rents. That is, his expected payoff is above his reservation payoff, 0. By the standard procedure, one can easily show, using i) of Lemma 1, that the expected information rents the producer receives are

$$\mathbf{E}V = \mathbf{E}[C'(s(\theta) - \theta)H(\theta)], \tag{8}$$

where $H(\theta) = [1 - F(\theta)]/f(\theta)$ is the inverse of the moral hazard. Following the common practice in contract theory, I impose the following regularity condition on $H(\theta)$.

Assumption 1. $H'(\theta) \leq 0$ a.e.

This assumption is satisfied by many commonly-used distribution functions, such as uniform and exponential distributions. As we will see, this assumption assures that quality varies systematically with the private information. However, the monotonicity condition requires that signal vary with the private information systematically.

The buyer chooses $s(\theta)$ to maximize his *virtual* surplus, which is her expected payoff net of information rents received by the producer:

$$\mathbf{E}[R(s(\theta) - \theta) - C(s(\theta) - \theta) - C'(s(\theta) - \theta)H(\theta)], \tag{9}$$

subject to the monotonicity condition given in ii) of Lemma 1.

For the moment, let us analyze the relaxed program by ignoring the monotonicity condition in the buyer's maximization program (9). If the solution to the relaxed program turns out to satisfy the monotonocity condition, then it is also a solution to the full program. Otherwise, one must introduce the monotonicity condition explicitly.

The first-order condition for the relaxed program is

$$R'(s(\theta) - \theta) - C'(s(\theta) - \theta) = C''(s(\theta) - \theta)H(\theta), \tag{10}$$

or $\quad R'(q(\theta)) - C'(q(\theta)) = C''(q(\theta))H(\theta).$ (10')

Assuming that the second-order condition is also satisfied. Differentiating s with respect to θ in (10), we have

$$ds/d\theta = [(H'(\theta) - 1)C''(q(\theta)) - R''(q(\theta)) - C'''(q(\theta))H(\theta)]/L_{ss}, \tag{11}$$

where $L_{ss} = R''(q(\theta)) - C''(q(\theta)) - C'''(q(\theta))H(\theta) < 0$.

Alternatively, differentiating q with respect to θ in (10'), we have

$$dq/d\theta = C''(q(\theta))H'(\theta)]/L_{ss} < 0. \tag{11'}$$

It is clear from (11) that the sign of $ds/d\theta$ is uncertain, as the sign of the denominator is uncertain. This is the case even when $\theta = \bar{q}$. Note that this happens because the benefit of quality to the buyer, R(q), is a function of the type parameter, θ, as $q = s - \theta$.

Alternatively, note that, in equilibrium, $s(\theta) = q(\theta) + \theta$. Hence, $ds/d\theta = dq/d\theta + 1$ is uncertainly signed, given that $dq/d\theta < 0$ in (11'). For simplicity, I limit myself to two polar cases in which $ds/d\theta$ is uniquely signed, i.e., $ds/d\theta$ is either positive or negative, for all θ.

Consider the first case where $ds/d\theta < 0$, for all θ (see Example 1 below). In this case, the solution to the relaxed program is optimal for the full program. The quality choice of the producer has the following property: except for the producer of type $\bar{q}$, there is an over-provision of quality by all other types of producer. Since $dq/d\theta < 0$, the lower θ is, the greater is quality over-provision.

In the second case, $dq/d\theta + 1 > 0$, for all θ (see Example 1 below). Thus, the monotonicity condition is not satisfied. Then, following the analysis of Guesnerie and Laffont (1984), we know that the solution involves bunching; all types of producer will produce at quality levels such that the signal is the same in all states. Denote the constant signal by s. It is easy to see that s satisfies that

$$\mathbf{E}[R'(s - \theta) - C'(s - \theta)] = \mathbf{E}[C''(s - \theta)H(\theta)]. \tag{12}$$

Note that, at the first-best quality level, q^*, the signal function, $s^* = q^* + \theta$, is increasing in θ. Define $s^*(q) = q^* + q$ and $s^*(\bar{q}) = q^* + \bar{q}$. Let us first show that $s > s^*(q)$, when $R''(q) - C''(q) < 0$, for all q.

Lemma 2. $s > s^*(q)$.

Proof. If $s \le s^*(q)$, then, $s - \theta \le s^*(q) - \theta \le s^*(q) - q$. When $R'(q) - C''(q) < 0$, $R'(s - \theta) - C'(s - \theta) \ge R'(s^*(q) - q) - C'(s^*(q) - q) = 0$, and the inequality is strict for $\theta \in (q, \bar{q}]$. Therefore, $\mathbf{E}[R'(s - \theta) - C'(s - \theta)] > 0$, which is obviously inconsistent with (12). Thus, we must have $s > s^*(q)$. Q.E.D.

On the other hand, it is well possible that s > s*($\bar{q}$), as shown in Example 1, implying that there is an over-production of quality for *all* types of producer.

This is an interesting result, as there are distortions for *all* types of producer. The reason for this is that the type parameter θ enters the buyer's valuation function, R(q), as q = s - θ.

Example 1. Let $R(q) = aq + b/2\, q^2$, $C(q) = dq + c/2\, q^2$, $a > d > 0$, $b < c < 0$.

If quality were observable, the first-best level of quality would be $q^* = (a - d)/(c - b)$.

Consider now the case where quality is not observable. Without consideration of the monotonicity condition, we know from (11') that $dq/d\theta = cH'(\theta)/(b - c) < 0$. Hence, $ds/d\theta = dq/d\theta + 1 = cH'(\theta)/(b - c) + 1 = x\, H'(\theta) + 1$, where $x = c/(b - c) > 0$. Clearly, when $x \geq -1/H'(\theta)$, for all θ, $ds/d\theta \leq 0$, indicating that the monotonicity condition is satisfied.

It is easy to check that, if the error term is uniformly distributed, then $F(\theta) = (\theta - \underline{q})/(\bar{q} - \underline{q})$, $\theta \in [\underline{q}, \bar{q}]$, and $H'(\theta) \equiv -1$. Hence, $ds/d\theta = -x + 1$. If $x \geq 1$, or $2c \leq b < c < 0$, $ds/d\theta \leq 0$, for all θ. Therefore, the solution to the relaxed program satisfies the monotonicity condition, and hence is also solution to the full program. Indeed, simple calculation shows that $s(\theta) = q^* + x\bar{q} + (1 - x)\theta$. Clearly, $ds/d\theta \leq 0$ if and only if $x \geq 1$. In this case, $q(\theta) = q^* + x(\bar{q} - \theta)$.

On the other hand, when $x < -1/H'(\theta)$, for all θ, $ds/d\theta > 0$, indicating that the monotonicity condition is not satisfied. Hence, the optimal signal-based contract involves bunching, $s(\theta) = s$, for all θ.

The constant s satisfies that $\mathbf{E}[a - d - (c - b)(s - \theta) - cH(\theta)] = 0$. Solving for s, we have $s = (a - d)/(c - b) + \mathbf{E}\theta + x\,\mathbf{E}[H(\theta)] = q^* + \mathbf{E}\theta + x(\mathbf{E}\theta - \underline{q})$, where use is made of that fact that $\mathbf{E}[H(\theta)] = \mathbf{E}\theta - \underline{q}$.

Recall that $q^* = (a - d)/(c - b)$ is the first-best quality level. Since $q(\theta) = s - \theta$, $q(\bar{q}) > q^*$ if and only if $\mathbf{E}\theta + x(\mathbf{E}\theta - \underline{q}) > \bar{q}$. Note that, for all $\theta < \bar{q}$, $q(\theta) > q(\bar{q})$.

If θ is uniformly distributed over the interval $[\underline{q}, \bar{q}]$, then $H'(\theta) \equiv -1$, and $\mathbf{E}\theta = (\underline{q} + \bar{q})/2$. For $ds/d\theta > 0$, it is required that $x < 1$. It can be easily verified that, for $0 < x < 1$, $\underline{q} < \mathbf{E}\theta + x(\mathbf{E}\theta - \underline{q}) < \bar{q}$. Hence, there exists a $\theta^* \in (\underline{q}, \bar{q})$, such that, for $\theta \in [\underline{q}, \theta^*)$, $q(\theta) > q^*$; for $\theta = \theta^*$, $q(\theta) = q^*$; and for $\theta \in (\theta^*, \bar{q}]$, $q(\theta) < q^*$.

I now show that there are parameter configurations under which all types of producer over-produce quality. Note first that, for the uniform distribution, as $x \to 1$, $\mathbf{E}\theta + x(\mathbf{E}\theta - \underline{q}) \to \bar{q}$. Hence, $s \to s^*(\bar{q})$.

Let us now perturb the uniform distribution and shift more weight toward the top end. This, for example, can be achieved by perturbing the constant density function and changing it into a two-step density function. The density function after perturbation is discontinuous only at one point. So, it is continuous almost everywhere. Consequently, Lemma 1 is not affected; what is really required is that the signal schedule be monotonic almost everywhere. Alternatively, we can obtain a continuous function by continuing the process above and constructing a continuum of step functions whose approximation is the continuous function.

For the so-constructed distribution function, $2\mathbf{E}\theta > \underline{q} + \bar{q}$. Hence, $\mathbf{E}\theta + x(\mathbf{E}\theta - \underline{q}) > \bar{q}$, as $x \to 1$. Thus, $s > s^*(\bar{q})$, implying that there is an over-provision of quality for all types of producer.

The price in state θ is given by $p = C(q(\underline{q})) = d(s - \underline{q}) + c/2\,(s - \underline{q})^2$, and hence is independent of quality $q(\theta) = s - \theta$, as s is a constant.

3. Conclusion

The paper analyzes a producer's incentive to provide quality of an information good. A buyer cannot observe the quality of the information good before purchase but only a signal which is the sum of quality and a noise. The marginal cost of quality provision for the information good is decreasing. I show that the producer has an incentive to over-supply quality. Moreover, and interestingly, *all* types of producer may over-supply quality.

It is assumed in the paper that the relationship between the producer and the buyer is one-shot. One can allow for repeated purchases. For example, one can consider a two-period model in which a buyer observes (but cannot verify) the quality of the producer’s product in the first period, and decides whether or not to continue the relationship with the producer, assuming that the probability that the buyer sticks to the producer increases with the observed quality of the producer’s product she bought in the first period. The reputation concern may give the producer an additional incentive to provide quality of information goods.

References

Bac, M. (2000) “Switching Costs and Screening Efficiency of Incomplete Contracts” *Canadian Journal of Economics* **33**, 1034-1048.

Chen, Y. (2000) “Promises, Trust, and Contracts” *Journal of Law, Economics, & Organization* **16**, 209-232.

Fudenberg, D. and J. Tirole, J. (1991) *Game Theory* MIT Press, Cambridge.

Grimm, B. (1998) “Price Indexed for Selected Semiconductors: 1974-1996” *Survey of Current Business* **78**, 8-24.

Guesnerie, R. and J. Laffont (1984) “A Complete Solution to a Class of Principal-Agent Problems with an Application to the Control of a Self-Managed Firm” *Journal of Public Economics* **25**, 329-369.

Hart, O. and J. Moore (1990) “Property Rights and the Nature of the Firm” *Journal of Political Economy* **98**, 1119-1158.

Jorgenson, D. (2001) “Information Technology and the U.S. Economy” *American Economic Review* **91**, 1-32.

Lewis, L. and D. Sappington (1988) “Regulating a Monopolist with Unknown Demand” *American Economic Review* **78**, 986-998.

MacLeod, B. and M. Malcomson (1988) “Reputation and Hierarchy in Dynamic Models of Employment” *Journal of Political Economy* **96**, 832-854.

Moore, G. (1965) “Cramming More Components onto Integrated Circuits” *Electronics* **38**, 114-117.

von Ungern-Sternberg, T. and von Weizsäcker, C. (1985) “The Supply of Quality on a Market for "Experience Goods"” in Geroski, P., L. Phlips and A. Ulph (eds.), *Oligopoly, Competition and Welfare* Basil Blackwell, Oxford.