Note on Quality Monitoring

by

*Tracy R. Lewis**

and

*David E. M. Sappington***

Revised August 1990

* University of California, Davis.
** Bellcore and the University of Florida.

Financial support from the National Science Foundation, the University of California Energy Research Group, and the Public Utility Research Center at the University of Florida is gratefully acknowledged. We thank Julio Rotemberg and Hal Varian for very helpful comments.

ABSTRACT

We consider a procurement problem in which the quality of the delivered product can be observed perfectly by the buyer and supplier, but may not be verifiable, i.e., may not be observable to any third party. We present a set of plausible conditions under which the equilibrium welfare of both the buyer and supplier is higher when quality is verifiable than when it is unverifiable. The welfare gain for the privately-informed supplier arises even when the buyer has all the bargaining power. Thus, the interests of the buyer and supplier coincide with regard to whether delivered quality should be made verifiable.

1. Introduction.

There are generally many characteristics of a product on which contracts for purchase and delivery are based. Price and quantity are perhaps the two most obvious characteristics. Quality is another. Quality, of course, may be difficult to measure and quantify in some circumstances, particularly for a party other than the buyer or supplier in the transaction. For example, when the Department of Defense (DOD) purchases a military tank, it may be extremely costly if not impossible for either DOD or the tank's manufacturer to prove in court the exact performance features of the tank under combat conditions. Similarly, although the supplier and buyer of a computer software package may both know precisely the level of assistance and instruction that the supplier provided, neither may be able to document this level conclusively to a third party.

In both these instances, the level of quality delivered is *unverifiable*; that is, it cannot be observed by a third party. Consequently, any contract the buyer and seller might write in which required payments vary with the level of quality supplied would not be enforceable.

A number of authors have considered the complications that arise when it is not possible to contract on critical aspects of a transaction. (See, for example, Clive Bull [1983], Sanford Grossman and Oliver Hart [1986], Jean Tirole [1986], and Oliver Williamson [1985].) To our knowledge, however, these studies have not focused on the issue of which parties gain and which parties lose when a critical variable is unverifiable. In this note, we describe a setting in which even though the supplier is the Stackelberg follower, both he and the buyer realize strict gains in equilibrium when quality is verifiable.[1]

It is not surprising that the buyer gains when quality is verifiable. An improved ability to tailor compensation to the level of delivered quality enables this Stackelberg leader to better motivate the supplier to provide quality.[2] The more surprising finding is that the supplier may also gain systematically when quality is verifiable. It is straightforward to construct settings in which the supplier will be worse off when a third party is able to observe the level of delivered quality. For example, when the level of quality signals perfectly the supplier's total production costs, the buyer can extract all rents from the supplier if quality is verifiable, whereas the supplier can generally secure some rents if quality cannot be verified. In the setting we consider, however, the level of quality is determined in part by the supplier's unobservable effort level. In this case, strict Pareto gains may arise when quality is verifiable, as we demonstrate below. Thus, under the identified conditions, there is a coincidence of preferences as to whether a public monitor of delivered quality should be available.

This line of research is important because it can provide insight regarding the structure of monitoring arrangements in procurement relationships. When the buyer and supplier both benefit from a more accurate public monitor of quality, they are likely to agree on institutional structures that facilitate third-party verification (e.g., testing and on-site inspections by independent parties). When the expected returns from public monitoring of quality are inversely related for the two parties, however, such agreement on the ideal monitoring structure seems less likely.[3]

The analysis proceeds as follows. The essential elements of our model are outlined in section 2. In section 3, the optimal contract for the buyer is described for the case where quality is verifiable. The corresponding contract when quality is not verifiable is characterized in section 4. A comparison of the two contracts is presented in section 5. Section 6 presents some concluding thoughts, including a discussion of the extent to which our findings are likely to generalize to other settings. We report, for example, that when an imperfect public monitor of delivered quality is available in the natural counterpart to the setting considered here, the welfare of both the buyer and supplier increases with the accuracy of the monitor. However, we also point out that the demonstrated coincidence of preferences will not hold in all settings. Thus, our analysis may best be viewed as deriving a class of examples in which the supplier will not wish to reduce the degree to which delivered quality is verifiable. The precise extent to which this conclusion can be generalized is left for further research.

2. Description of the Model.

Intuitively, the essential task of the buyer in our model is to motivate the supplier to provide a high-quality product, while limiting the supplier's rents. The supplier may earn rents because the costs he incurs to improve quality cannot be observed by the buyer. Furthermore, the supplier has private knowledge of his innate capabilities.

Formally, we let $v_0 \in [\underline{v}, \overline{v}]$ represent the base level of quality, i.e., the level the supplier can deliver if he incurs no effort to improve quality. v_0 is known to the supplier, but not to the buyer. The buyer's beliefs about v_0 are represented by the density function

$f(v_0) > 0 \ \forall \ v_0 \in [\underline{v}, \bar{v}]$. The corresponding distribution function is denoted $F(v_0)$. We assume $\frac{d}{dv_0}\left\{\frac{1 - F(v_0)}{f(v_0)}\right\} \leqq 0 \quad \forall \ v_0 \in [\underline{v}, \bar{v}]$.[4]

The supplier can increase quality above its base level through the expenditure of effort, e. One unit of effort increases overall quality, v, by one unit, i.e., $v = v_0 + e$. The cost to the supplier of delivering effort level e is denoted $D(e)$. These unobservable development costs increase with e, i.e., $D'(e) > 0 \ \forall e > 0$. Furthermore, the rate at which these costs increase with e is assumed to be an increasing, convex function of e, i.e., $D''(e) > 0$ and $D'''(e) \geqq 0 \ \forall e > 0$. One implication of these assumptions is that there are effectively diminishing returns to the supplier's efforts to enhance quality. The level of effort supplied by the supplier to improve quality cannot be observed by the buyer. Thus, even though the buyer can observe the level of quality (v) that is provided, he cannot determine the portion of overall quality due to the supplier's efforts.[5]

The transaction between buyer and supplier is governed by two-part tariffs. These tariffs consist of a unit transfer price, p, and lump sum payment, L, from buyer to supplier.[6] The buyer's final demand for the product in question is influenced both by price and by quality, v. The buyer's demand (or willingness to pay) function, $Q(p, v)$, is known to both the buyer and supplier, but not to any third party. As our leading case, we assume demand increases linearly with quality, and is diminished when p increases, i.e., $Q(p, v) = v + q(p)$, where $q'(p) < 0$.[7] For simplicity, we abstract from income effects, so $Q(\cdot)$ does not depend on L. We also assume the buyer's demand is a concave function of price, so $q''(p)$

$\equiv Q_{pp}(p, v) \leqq 0.$

The supplier's marginal cost of production is assumed to be known to all parties, and not to vary with output or quality. Thus, $C(Q, v) = k + c\,Q$, where c and k are positive constants, and $C(Q, v)$ represents the total cost of producing Q units of output, each of quality v. The extent to which our basic conclusions are altered when more general cost structures are admitted is considered in section 6. One interpretation of the simple cost structure we examine is that all the costs of providing higher quality are of a lump sum variety. For example, a tank's ability to maneuver on the battlefield may depend entirely on the nature of the tank's basic design and engineering, rather than on the particular materials used to manufacture each tank. Similarly, the physical cost of producing a piece of computer software may well be independent of the level of assistance and instruction provided by a salesperson.

The supplier's objective is to maximize expected monetary profit less his costs of supplying quality. The supplier's monetary profit consists of revenues from sales to the buyer less production costs, i.e., $p{\cdot}Q(p, v) + L - [c\,Q(p, v) + k]$.

The buyer is the Stackelberg leader in our model. She designs a menu of two-part tariffs from which the supplier makes a binding choice. The buyer's objective is to maximize her expected surplus, $S(p, v) \equiv \int_p^\infty Q(\zeta, v)d\zeta$, less the lump sum payment she makes to the supplier. The exact nature of the payment options the buyer offers to the supplier will depend upon whether delivered quality is verifiable or unverifiable.

3. Verifiable Quality.

When quality is verifiable, the buyer can dictate a quality level that must accompany any two-part tariff selected by the supplier. Without loss of generality, equilibrium payments and quality levels can be represented as functions of the supplier's truthful report of his innate quality level, v_0.[8] Thus, we can identify $\{p(v_0), L(v_0)\}$ as the two-part tariff the supplier will select when his innate quality level is v_0. $v(v_0)$ will denote the corresponding quality level that is delivered. Employing this notation, the buyer's problem when quality is verifiable, [BP-V], is:

$$\underset{p,\, v,\, L}{\mathit{Maximize}} \int_{\underline{v}}^{\overline{v}} \left\{ S(p(v_0),\, v(v_0)) - L(v_0) \right\} f(v_0)\, dv_0$$

subject to, $\forall\ v_0,\ \hat{v}_0 \in [\underline{v}, \overline{v}]$:

$$\pi(v_0) \equiv \pi(v_0 | v_0) \geq \overline{\pi}, \text{ and} \tag{3.1}$$

$$\pi(v_0) \geq \pi(\hat{v}_0 | v_0), \tag{3.2}$$

where $$\pi(\hat{v}_0 | v_0) \equiv [p(\hat{v}_0) - c]Q(p(\hat{v}_0), v(\hat{v}_0)) - k + L(\hat{v}_0) - D(v(\hat{v}_0) - v_0). \tag{3.3}$$

The individual rationality constraints (3.1) ensure the supplier expects to earn at least his reservation wage, $\overline{\pi}$, when he contracts with the buyer. The incentive compatibility constraints (3.2) state that, in equilibrium, the supplier will be induced to report his innate ability level, v_0, truthfully. Notice that in (3.3) we have substituted $v - v_0$ for the firm's effort, e (since $v = v_0 + e$).

The optimal contract for the buyer in this setting is described in Proposition 1. The statement of the proposition makes reference to $W(p, v|v_0) \equiv S(p, v) + [p - c]Q(p, v) - D(v - v_0) - k$, which is simply the total realized surplus of the buyer and supplier when the unit transfer price is p, the delivered quality level is v, and the supplier's innate ability level is v_0.

Proposition 1. The solution to [BP-V] has the following properties $\forall\, v_0 \in [\underline{v}, \overline{v}]$:[9]

(i) $p(v_0) = c$;

(ii) $v'(v_0) \geq 0$:

(iii) $\pi(v_0) = \overline{\pi} + \int_{\underline{v}}^{v_0} D'(v(\xi) - \xi)\, d\xi$; and

(iv) $W_v(p(v_0), v(v_0)|v_0) - D''(v(v_0) - v_0)\left[\dfrac{1 - F(v_0)}{f(v_0)}\right] = 0.$

The central finding in Proposition 1 is property (i), which reports that when quality is verifiable, pricing distortions are not employed to motivate the supplier. All incentives for quality provision are provided by careful structuring of the lump sum payment and the level of quality that is called for. More quality is motivated the higher the supplier's innate quality level, v_0. (See property (ii).) Furthermore, the supplier earns rents which increase with v_0. (See property (iii).) To limit these rents, the induced level of quality falls short of the surplus-maximizing level $\forall\, v_0 < \overline{v}$. (See property (iv) of Proposition 1.)

Thus, when quality is verifiable, the problem of motivating its delivery is optimally separated from the problem of pricing the supplier's product.[10] Any distortions designed to control the supplier's rents come in the form of inducing too little quality relative to the ideal; and these distortions are implemented via lump sum payments, not through unit transfer prices. A different conclusion emerges, however, if quality is unverifiable.

4. Unverifiable Quality.

When the level of delivered quality is not verifiable, the buyer cannot explicitly dictate a quality level that must accompany any two-part tariff selected by the supplier. Formally, the buyer's problem when quality is unverifiable, [*BP-U*], is the following:

$$\underset{p^u(\cdot),\, L^u(\cdot)}{Maximize} \int_{\underline{v}}^{\overline{v}} \left\{ S(p^u(v_0),\, v^u(p^u(v_0),\, v_0)) \;-\; L^u(v_0) \right\} f(v_0)\, dv_0$$

subject to $\forall\, v_0,\, \hat{v}_0 \in [\underline{v}, \overline{v}]$:

$$\pi^u(v_0 | v_0) \geqq \overline{\pi}\,; \tag{4.1}$$

$$\pi^u(v_0 | v_0) \geqq \pi^u(\hat{v}_0 | v_0)\,; \text{ and} \tag{4.2}$$

$$v^u(p,\, v_0) \;=\; \underset{v}{argmax}\, [p - c]Q(p,\, v) - D(v - v^0)\,, \tag{4.3}$$

where $\pi^u(\hat{v}_0 | v_0) \equiv [p^u(\hat{v}_0) - c]\, Q(p^u(\hat{v}_0),\, v^u(p^u(\hat{v}_0),\, v_0))$

$$- k + L^u(\hat{v}_0) - D(v^u(p^u(\hat{v}_0),\, v_0) - v_0).$$

Constraints (4.1) and (4.2), respectively, are the individual rationality and incentive compatibility constraints corresponding to (3.1) and (3.2) in [*BP-V*]. (4.3) reflects the additional restriction on the buyer that the supplier will choose to supply the level of quality that maximizes his profits, given the base quality level, v_0, and the selected unit transfer price, p. The solution to [*BP-U*] is recorded in Proposition 2. In the statement of the

Proposition and in the ensuing analysis, we will sometimes write $v^u(p^u(v_0), v_0)$ as $v^u(v_0)$, where there is no possibility of confusion.

Proposition 2. The solution to [*BP-U*] has the following properties $\forall\, v_0 \in [\underline{v}, \overline{v}]$:

(i) $p^u(v_0) > c$;

(ii) $\dfrac{\partial v^u(p^u, v_0)}{\partial p^u} > 0$;

(iii) $\pi^u(v_0 | v_0) = \overline{\pi} + \int_{\underline{v}}^{v_0} D'(v^u(\xi) - \xi)d\xi$; and

(iv) $$[p^u(v_0) - c]Q_p(p^u(v_0), v^u(v_0)) + \left\{ W_v(p^u(v_0), v^u(v_0)|v_0) - D''(v^u(v_0) - v_0)\, \frac{1 - F(v_0)}{f(v_0)} \right\} \frac{\partial v^u(\cdot)}{\partial p^u(\cdot)} = 0.$$

Property (i) of Proposition 2 follows from relation (4.3): the supplier will only raise quality above the base level if the transfer price is set above the marginal cost of production. Therefore, it follows from properties (ii) and (iv) in Proposition 2 that the induced level of quality, $v^u(p^u(v_0), v_0)$, will be strictly less than the level that maximizes total net surplus, $W(p, v | v_0)$. This is the case even for the highest base quality level, $\overline{v}$. Thus, not only are the quality distortions generally of different magnitude when quality is unverifiable, but pricing distortions also arise in this case. A more detailed comparison of the two cases is presented in section 5.

5. A Comparison.

It is apparent that the buyer's objective function cannot take on a higher value in the solution to [*BP-U*] than it does in the solution to [*BP-V*]. The solution to [*BP-U*] is a feasible solution to [BP-V] since the buyer could always induce the profit-maximizing level of quality; but she chooses not to do so. In fact, more detailed comparisons of the solutions to the two problems are possible. Unit transfer prices, lump sum payments, quality levels, profits and welfare can all be ranked in the two solutions, as reported in Proposition 3.

Proposition 3. A comparison of the solutions to [*BP-V*] and [*BP-U*] reveals that $\forall\ v_0 \in [\underline{v}, \overline{v}]$:

(i) $p^u(v_0) > p(v_0)$;

(ii) $L^u(v_0) < L(v_0)$;

(iii) $v(v_0) > v^u(v_0)$;

(iv) $\pi(v_0|v_0) \geqq \pi^u(v_0|v_0)$, with strict inequality for all $v_0 > \underline{v}$; and

(v) $S(p(v_0), v(v_0)) > S(p^u(v_0), v^u(v_0))$.

The first comparison in Proposition 3 is an important one. When quality is verifiable, the production and quality-delivery problems can effectively be separated. Thus, with production costs known, marginal cost transfer prices can be implemented, and lump sum payments can be adjusted to provide the requisite incentives for quality supply. When quality is unverifiable, however, its level cannot be mandated. Instead, the supplier must find it in his own interest to undertake the output expansion that results from increased quality. The buyer ensures this by establishing transfer prices in excess of marginal production cost. The price-cost margin is what makes output expansion profitable for the supplier.

Of course, by setting the transfer price above marginal cost, the total surplus that will be achieved *ex post* is reduced. Consequently, inducing the delivery of quality is more costly for the buyer when quality is unverifiable. Therefore, in trading off the benefits and costs of supplying quality, the buyer optimally induces less quality from the supplier when quality levels cannot be verified, as reported in property (iii) of Proposition 3.

Notice from property (iii) of Propositions 1 and 2 that the supplier generally commands rents from his private knowledge of the base quality level, v_0. These rents increase with v_0 since the higher is the base quality level, the greater is the supplier's ability to misrepresent innate quality as the product of his own efforts. Notice also that the supplier's rents increase with v_0 at a rate given by the marginal cost of effort, $D'(v - v_0)$. Therefore, due to the increasing marginal cost of supplying effort, the supplier's rents will increase with v_0 more rapidly the higher the induced quality level. Hence, the supplier's profit will be greater for each realization of base quality, $v_0 > \underline{v}$, when quality is verifiable than when it is unverifiable.

Moreover, the increase in the supplier's profit is only a fraction of the increase in total surplus that arises when the level of quality that is supplied can be verified by a third party. When quality is verifiable, distortions in transfer prices need not be implemented to motivate the supply of quality. This leads to a direct gain in total realized surplus. Furthermore, because quality is less costly to motivate, more is induced. The increased quality level directly enhances the buyer's level of realized surplus. The enhanced supply of quality also enables the the supplier to secure greater rents. However, the increase in rents that accrue to the supplier is outweighed by the increase in total surplus that is generated from the higher level of quality that is secured at lower cost. Hence, under the specified conditions, both the buyer and the supplier prefer to have quality verifiable rather than unverifiable.

6. Conclusions and Extensions.

The intent of this note was simply to derive a set of plausible conditions under which a buyer and supplier will both prefer that the level of delivered quality be verifiable. This coincidence of preferences arose in our model because more quality is induced when quality is verifiable. The higher induced quality enhances the buyer's welfare directly, and also improves her welfare indirectly by limiting the need to distort price above the marginal cost of production in order to better motivate the supply of quality. The supplier gains from the higher induced quality levels because he must be compensated for his efforts according to the marginal disutility these efforts entail. With increasing marginal costs of delivering quality, the supplier commands greater rents in equilibrium the higher the induced level of quality. However, the increased rents for the supplier are more than offset by the increase in total surplus generated by the higher level of quality and the reduced pricing distortions. Thus, both parties prefer the higher quality levels that are induced when quality is verifiable.

For simplicity, the analysis in this note focused on the two extreme cases where the level of delivered quality was either perfectly observable or completely unobservable to a third party. More generally, one might consider an imperfect public monitor of delivered quality, and ask whether the buyer and supplier both prefer the most accurate such monitor. Under plausible conditions, the answer to this question is "yes."

More specifically, this conclusion will emerge if the *ex post* public signal, s, of quality is the realization of a normally distributed random variable with finite variance, $\sigma > 0$. The mean of this variable is the level of delivered quality. With the signal verifiable, *ex post* transfer payments, T, to the supplier can be conditioned both on his initial report of innate quality, $\hat{v}_0$, and on the realization of s. If there are no bounds on T, then regardless of the magnitude of σ, the risk-neutral buyer can always achieve the same expected welfare that she can secure when delivered quality is verifiable. She does so by rewarding the risk-neutral supplier generously for high realizations of s, and penalizing him severely for low realizations. (See Baron and Besanko [1984] and Michael Riordan and Sappington [1988].)

When *ex post* payments are bounded above and below, however, the discipline that can be provided by the imperfect public monitor is limited. For sufficiently large values of σ, the buyer will raise the unit transfer price, p, above marginal cost to better motivate the supplier to enhance the level of delivered quality, just as in the case where quality is entirely unverifiable. Even with the extra incentive created by the pricing distortions, the equilibrium level of induced quality falls with σ, and the welfare of both the buyer and supplier declines with σ. (For details, see Lewis and Sappington [1989].) Thus, the essential conclusions of this note extend in straightforward fashion to analogous settings where the accuracy of a public monitor of quality varies continuously.[11]

An important issue for future research is the extent to which the identified coincidence of preferences will persist in still different settings. One scenario in which this will be the case is the natural extension of the present setting to the case of multiple quality dimensions. An interesting complication that can be explored here is the fact that some quality attributes may be verifiable while others are not. One can show that the induced levels for the verifiable quality attributes will vary according to whether these attributes are substitutes or complements for the quality attributes that cannot be verified by a third party.

Remaining in the uni-dimensional quality setting, one could consider different production technologies. In particular, production costs might vary with the product's quality. In this case, the welfare comparisons corresponding to those drawn in Proposition 3 will not necessarily hold. When marginal production costs vary with quality, the supplier's effort will affect the realized marginal cost. Consequently, unit transfer prices will generally be distorted away from marginal cost to better motivate the supplier.[12] These distortions can complicate any systematic welfare comparisons, as can a positive relationship between quality level and marginal production cost.[13] When marginal production costs rise with the level of delivered quality, these costs will be higher when quality is verifiable, presuming more quality is induced when quality is verifiable. The higher marginal costs can result in higher unit transfer prices, even if these prices are closer to marginal cost than when quality is not verifiable. Consequently, overall welfare comparisons may be more difficult to draw.

Our formulation of the buyer's preferences also facilitated the welfare comparisons drawn in Proposition 3. While some generalizations are possible, the comparisons may not be robust to all specifications of the buyer's demand function. For instance, suppose the buyer's demand is more sensitive to quality the higher the final unit price (i.e., $Q_{pv}(\cdot) > 0$). In this case, the equilibrium unit price continues to be higher when quality is unverifiable than when it is verifiable. Now, however, the higher unit price could lead the buyer to induce *more* quality from the supplier in equilibrium, thereby increasing the supplier's rents. Thus, when the effects of price and quality on the buyer's demand are not separable, the buyer and supplier may no longer agree that quality should be verifiable.

However, they will agree that quality should be verifiable in some settings where quality and quantity are substitutes rather than complements. To illustrate, consider the setting developed above with the single exception that the buyer's demand is given by $Q(p, v) = -v + q(p)$. Thus, a unit increase in quality reduces by one unit the quantity of the product demanded. As an illustration, in a military procurement setting, a small number of swift, accurate aircraft may be as effective as a large number of slow, less lethal combat planes.[14] In this case where quality and quantity are substitutes, the equilibrium welfare of both the buyer and supplier is again higher when quality is verifiable than when it is unverifiable. A fundamental difference arises in this setting, though. When quality is unverifiable, the unit price (p) is optimally set *below* marginal cost. Under this pricing structure, the supplier incurs a marginal loss on each unit that is purchased.[15] His incentives, therefore, are to limit the number of units the buyer demands. This reduction in demand can only be accomplished at the stipulated price by increasing the level of delivered quality. Hence, pricing distortions persist when quality is unverifiable but serves as a substitute for quantity; but now prices are distorted below rather than above marginal cost.

As noted in the introduction, the fact that both parties prefer quality to be verifiable in our model and its generalizations may depend critically on the presence of a moral hazard problem.[16] If the supplier had no opportunity to expend (unobservable) effort to improve quality and if the marginal production cost varied with quality, the buyer would prefer that the realized quality be verifiable while the supplier would prefer no information on quality be in the public domain. When quality is verifiable in this setting, the supplier's realized production costs would also be verifiable, and so the supplier could command no rents from his direct knowledge of v_0. If quality were unverifiable, however, the supplier could still earn rents from his private information. Thus, the buyer and supplier have opposing interests with regard to the monitoring of quality in this setting. We leave for future research a more general specification of when the preferences of a buyer and supplier will coincide, and when they will be in conflict.

In closing, we briefly mention two other settings where our analysis may be of some relevance. First, consider the task of a central management charged with establishing transfer prices within its organization. If the quality of the internal services is readily verified, there are sound economic reasons for setting transfer prices at the level of marginal cost. However, when quality is not verifiable and when central management has imperfect knowledge of the costs of providing quality, prices may optimally be established above or below marginal cost, depending upon whether quality and quantity are complements or substitutes.[17]

Second, consider a procurement setting where *ex ante* competition is introduced to help limit the rents of the contractor. When quality is not verifiable, bids for the right to serve as the contractor cannot credibly be conditioned on the level of quality to be delivered. Hence, bidding must take place over *ex post* compensation schedules (i.e., $\{p(\cdot), L(\cdot)\}$ pairs in our setting). In equilibrium, the firm with the highest innate quality level, v_0, will win the right to serve as the contractor. But this contractor will not deliver the final product at the lowest unit price, p. (Recall from the proof of Proposition 2 that $p^{u\prime}(v_0) \geq 0$.) Hence, when quality is unverifiable and quality and quantity are complements, optimal procurement will generally not select the contractor who bids the lowest unit delivery price. Furthermore, greater competition among potential contractors will generally result in a higher unit delivery price in equilibrium.[18]

These and related extensions of our analysis await further research.

FOOTNOTES

1. It is important to further distinguish our approach from the approach taken in other important studies in the literature on the provision of quality. A key difference is that in our model, the (single) buyer knows the exact level of quality of the product she is purchasing before the purchase decision is made. In other studies (e.g., Benjamin Klein and Keith Leffler [1981], Hayne Leland [1979], and Carl Shapiro [1983]) buyers cannot observe quality before formulating their purchase decisions. Hence, a firm's "reputation" for providing quality or some government certification of quality becomes an important determinant of a firm's sales to consumers.

   Leland [1979] examines the effects of improving consumers' information about quality by enforcing a minimum quality standard. In effect, a perfect binary signal of quality is introduced, where the actual level of quality is revealed to either exceed or fall short of a specified threshold level of quality. Leland cites conditions under which higher quality standards improve consumers' welfare, and specifies other conditions under which welfare losses ensue. Shapiro [1983] shows that when the speed with which consumers learn the quality of the product they have purchased increases, their equilibrium level of welfare also increases. However, competition among suppliers keeps their expected profits at zero, so strict Pareto gains from improved information do not arise in Shapiro's dynamic model. In both these models, it is the purchasers whose information is improved. In our model, the buyer's information is not improved. Only the precision of a public report of what the buyer and supplier both know improves.

A recent important study that is more closely related to our own is that of Laffont and Tirole [1989]. The authors examine the form of optimal incentive contracts to encourage cost reduction when the quality of the delivered product cannot be observed perfectly. In contrast to their work, our analysis focuses on the incentives of the buyer and supplier to secure objective and verifiable measurement of delivered quality.

2. Furthermore, the buyer could always choose not to base compensation on the realized level of quality, even when it is verifiable. Thus, the buyer who is endowed with full commitment abilities and the role of Stackelberg leader cannot be strictly worse off when quality is verifiable.

3. One could examine these incentives formally in an extended bargaining model where the buyer and supplier initially bargain over the precision of the public monitoring system that will be installed to govern their subsequent interactions.

4. This regularity condition on the distribution of v_0 is standard in the literature. As David Baron and David Besanko [1984] report, this condition is satisfied for a variety of common distributions, such as the uniform distribution.

5. It should be apparent that our model to this point is virtually identical to the model analyzed by Jean-Jacques Laffont and Jean Tirole [1986].

6. Although more general nonlinear compensation schemes are conceivable, our focus on two-part tariffs of this form reflects an interest in common and relatively simple pricing structures.

7. This separability and linearity assumption is overly strong, but convenient for expositional simplicity. Our main findings continue to hold in more general settings provided $Q_{vv}(p, v)$ and $Q_{pv}(p, v)$ are both nonpositive $\forall p, v$, and both are sufficiently small in absolute value. In section 6, we also consider the possibility that quantity and quality are substitutes, so that the quantity demanded at any price declines with quality.

8. This conclusion is simply an illustration of the revelation principle (e.g., Roger Myerson [1979]).

9. Throughout, we focus on interior solutions where the buyer optimally induces the supplier to provide strictly more than his innate level of quality for all v_0. The solution to [BP-V] (and [BP-U] below) will be interior provided the buyer's marginal value of quality is sufficiently large relative to the supplier's marginal cost of providing quality for small levels of quality.

10. Since the problems of setting transfer prices and motivating quality provision can be separated when quality is verifiable, the solution to [BP-V] is analogous to the solution to the procurement problem examined by Laffont and Tirole [1986]. For a detailed analysis of when pricing and incentive effects can be separated in a model where a regulator oversees the activities of a multiproduct firm, see Laffont and Tirole [1988].

11. Of course, if the *ex post* monitor is costly to employ or if the parties are risk averse, the imperfect public monitor will necessarily result in welfare losses relative to the case where quality is costlessly verifiable. (See Baron and Besanko [1987] for an analysis

of the optimal auditing policy with risk-averse parties.)

12. Deviations of price from marginal cost are also generally optimal when there is asymmetric information about production costs.

13. Systematic comparisons in more intricate environments may also be complicated by the possibility of general nonlinear tariffs. However, in the simple setting we considered, the main qualitative comparisons drawn in Proposition 3 will continue to hold when nonlinear tariffs are admitted. This is the case because marginal prices in excess of marginal production costs are necessary to induce the provision of quality when quality is unverifiable.

14. See F. Michael Scherer [1964], for example, for some evidence that quality and quantity are often substitutes in the military procurement setting.

15. Of course, the lump sum payment (L) is designed to compensate the supplier for the marginal losses he incurs in equilibrium.

16. Of course, the coincidence of preferences also depends on the presumption that there are diminishing returns in the production of quality (i.e., that $D''(\cdot) > 0$). While this assumption seems very plausible for high levels of quality, increasing returns are conceivable over some range of quality levels.

17. For an interesting analysis of the transfer pricing issue, but one which does not consider quality issues, see Milton Harris, Charles Kriebel and Artur Raviv [1982].

18. When quality and quantity are substitutes (i.e., when $Q_v(p, v) = -1$), however, $p^{u\prime}(v_0) \leq 0 \; \forall \; v_0$. Thus, higher innate quality levels are associated with lower unit prices. Therefore, the contractor selected will be the one who offers to supply at the lowest unit price. Furthermore, greater competition generally will result in a lower unit price in equilibrium.

APPENDIX

Proof of Proposition 1.

We proceed along standard lines by replacing the global incentive compatibility constraints (3.2) with their local counterparts, which require only $\pi_1(\hat{v}_0|v_0)|_{\hat{v}_0=v_0} = 0$. ($\pi_i(\cdot)$ denotes the partial derivative of $\pi(\cdot)$ with respect to its i'th argument, $i = 1, 2$.) Then we verify that (3.2) is satisfied $\forall\, v_0 \in [\underline{v}, \overline{v}]$ at the solution that is derived. (For additional discussion and illustration of this approach, see, for example, Baron and Myerson [1982] or Roger Guesnerie and Laffont [1984].)

To begin, notice that the local compatibility constraints imply

$$\pi_2(\hat{v}_0|v_0)|_{\hat{v}_0=v_0} = D'(v(v_0) - v_0). \tag{A1.1}$$

The second order conditions require $\pi_{11}(\hat{v}_0|v_0)|_{\hat{v}_0=v_0} \leqq 0 \;\; \forall\, v_0$. Thus, since (A1.1) must hold $\forall\, v_0 \in [\underline{v}, \overline{v}]$, differentiation of (A1.1) with respect to v_0 provides

$$\pi_{12}(\hat{v}_0|v_0)|_{\hat{v}_0=v_0} = D''(v(v_0) - v_0)\,v'(v_0) \geqq 0. \tag{A1.2}$$

Therefore, since $D''(\cdot) > 0$ by assumption, we must have $v'(v_0) \geq 0 \;\; \forall\, v_0 \in [\underline{v}, \overline{v}]$. Provided this condition holds at the identified solution, the incentive compatibility constraints will be satisfied globally.

From (A1.1), equilibrium profit increases with v_0. Thus, (3.1) is optimally satisfied with $\pi(\underline{v}|\underline{v}) = \overline{\pi}$. Hence,

$$\pi(v_0 | v_0) = \bar{\pi} + \int_{\underline{v}}^{v_0} D'(v(\xi) - \xi) d\xi. \tag{A1.3}$$

Next, we can express the objective function in [*BP-V*] as the expected total surplus, $W(\cdot)$, less the supplier's profit, $\pi(\cdot)$, i.e.,

$$\int_{\underline{v}}^{\bar{v}} \left\{ W(p(v_0), v(v_0) | v_0) - D'(\cdot) \frac{1 - F(v_0)}{f(v_0)} \right\} dF(v_0), \tag{A1.4}$$

where we have evaluated $\int_{\underline{v}}^{\bar{v}} \pi(\cdot) dF(v_0)$ using (A1.3) and integration by parts. Now, pointwise maximization of (A1.4) with respect to $p(\cdot)$ and $v(\cdot)$ yields properties (i) and (iv) of Proposition 1.

What remains is to verify that second order condition (A1.2) is satisfied at the solution to [BP-V]. Differentiation of property (iv) in the Proposition yields

$$\frac{dv(\cdot)}{dv_0} = \frac{D''(\cdot) \frac{d}{dv_0} \left[\frac{1 - F(v_0)}{f(v_0)} \right] - D'''(\cdot) \frac{1 - F(\cdot)}{f(\cdot)} - W_{vp}(\cdot) p'(v_0) - W_{vv_0}(\cdot)}{W_{vv}(\cdot) - D'''(\cdot) \frac{1 - F(\cdot)}{f(\cdot)}}. \tag{A1.5}$$

The first two terms in the numerator of the right hand side of (A1.5) are negative, given our assumptions that $\dfrac{d}{dv_0}\left[\dfrac{1 - F(v_0)}{f(v_0)}\right] \leq 0$, $D''(\cdot) > 0$, and $D'''(\cdot) \geq 0$. The third term is zero since with $p(v_0) = c \; \forall \, v_0$ at the solution to [BP-V], $p'(v_0) = 0 \;\; \forall \, v_0$. The last term is positive since $W_{wv_0} = D''(\cdot) > 0$. Also, since $W_{vv}(\cdot) = S_{vv}(\cdot) - D''(\cdot)$, and since $S_{vv}(\cdot) = 0$ when $Q(p, v) = v + q(p)$, we have $W_{vv}(\cdot) < 0$. Hence, the denominator of the fraction is strictly negative, so $v'(v_0) \geq 0$ as required. ■

Proof of Proposition 2.

The proof proceeds in much the same manner as the proof of Proposition 1. The local incentive compatibility constraints require

$$\pi_2^u(v_0 \,|\, v_0) = D'(v^u(p^u(v_0), v_0) - v_0). \tag{A2.1}$$

The second order conditions require

$$\pi_{12}^u(v_0 \,|\, v_0) = D''(v^u(\cdot) - v_0) \cdot \frac{\partial v^u(p^u(v_0), v_0)}{\partial p} \cdot p^{u\prime}(v_0) \geq 0. \tag{A2.2}$$

From (4.3), $\dfrac{\partial v^u(\cdot)}{\partial p} = [D''(\cdot)]^{-1} > 0$, so (A2.2) requires $p^{u\prime}(v_0) \geq 0$. Also notice from (4.3) that $p^u(v_0)$ must exceed c for all $v_0 \in [\underline{v}, \overline{v}]$ to ensure $v^u(\cdot) > v_0$.

Now, using (A2.1) to express the supplier's profit as a function of v_0 and integrating by parts, the buyer's objective function can be rewritten as:

$$\int_{\underline{v}}^{\bar{v}} \left\{ W(p^{u}(v_0), v^{u}(\cdot)|v_0) - D'(\cdot)\frac{1 - F(v_0)}{f(v_0)} \right\} dF(v_0). \tag{A2.3}$$

Pointwise maximization with respect to $p^{u}(v_0)$ then yields property (iv) in Proposition 2.

What remains is to ensure (A2.2) holds at the identified solution. It follows from (4.3) that with $Q_v(p, v) = 1 \; \forall \, p, v$, we have $v_1^{u}(p, v_0) = \frac{1}{D''(\cdot)} > 0$, $v_2^{u}(p, v_0) = 1$, $v_{11}^{u}(p, v_0) \leq 0$, and $v_{12}^{u}(p, v_0) = 0$. Using these facts, differentiation of the equation in property (iv) of Proposition 2 yields:

$$\left\{ [p - c]Q_{pp}(\cdot) + Q_p(\cdot) + G(\cdot)v_{11}^{u}(\cdot) + v_1^{u}(\cdot)\left[W_{vp}(\cdot) + W_{vv}(\cdot)v_1^{u}(\cdot) - D'''(\cdot)\frac{1 - F(\cdot)}{f(\cdot)} \right] \right\} dp$$

$$+ v_1^{u}(\cdot)\left[W_{vv}(\cdot) + W_{vv_0}(\cdot) - D''(\cdot)\frac{d}{dv_0}\left(\frac{1 - F(\cdot)}{f(\cdot)} \right) \right] dv_0 = 0, \tag{A2.4}$$

where $G(\cdot) \equiv W_v(p^{u}(v_o), v^{u}(\cdot)|v_0) - D''(\cdot)\,\dfrac{1 - F(v_0)}{f(v_0)} \geq 0$. The inequality follows directly from property (iv) of Proposition 2, using properties (i) and (ii).

Finally, notice that $W_v(p, v|v_0) = [p - c] + \int_p^{\infty} Q_v(\xi, v)\, d\xi - D'(v - v_0)$; so with $Q_v(p, v) = 1 \; \forall \, p, v$, it follows that $W_{vp}(\cdot) = 0$ and $W_{vv}(\cdot) = - W_{vv_0}(\cdot) = - D''(v - v_0) < 0$.

Hence, with $v_1^u(\cdot) = \frac{1}{D''(\cdot)}$, (A2.4) implies

$$\frac{dp^u(v_0)}{dv_0} = \frac{\frac{d}{dv_0}\left(\frac{1 - F(\cdot)}{f(\cdot)}\right)}{[p - c]Q_{pp}(\cdot) + Q_p(\cdot) + G(\cdot)v_{11}^u(\cdot) - \left[1 + D'''(\cdot)\frac{1 - F(\cdot)}{f(\cdot)}\right]v_1^u(\cdot)}. \tag{A2.5}$$

Given the maintained assumptions of $\frac{d}{dv_0}\left(\frac{1 - F(v_0)}{f(v_0)}\right) \leqq 0$, $D''(e) > 0$, $D'''(e) \geqq 0$, and $Q_{pp}(\cdot) \leqq 0$, the right hand side of (A2.5) is nonnegative, so (A2.2) is satisfied at the identified solution. ■

Proof of Proposition 3.

We begin by proving $v(v_0) > v^u(v_0)\ \forall\, v_0$. From property (iv) in Propositions 1 and 2,

$$W_v(p^u, v^u | v_0) - D''(v^u - v_0)\frac{1 - F(v_0)}{f(v_0)}$$

$$> W_v(p, v | v_0) - D''(v - v_0)\frac{1 - F(v_0)}{f(v_0)} = 0, \tag{A3.1}$$

where we have suppressed the dependence of $p^u(\cdot)$, $v^u(\cdot)$, $p(\cdot)$, and $v(\cdot)$ on v_0. Hence, from the definition of $W(\cdot)$ and from property (i) in Proposition 1, (A3.1) provides:

$$\int_{p^u}^{\infty} Q_v(\xi, v^u)d\xi + [p^u - c]Q_v(p^u, v^u) - D'(v^u - v_0) - D''(v^u - v_0)\frac{1 - F(v_0)}{f(v_0)}$$

$$> \int_{c}^{\infty} Q_v(\xi, v)d\xi - D'(v - v_0) - D''(v - v_0)\frac{1 - F(v_0)}{f(v_0)}. \tag{A3.2}$$

Therefore, with $Q_v(\cdot) = 1$, (A3.2) reduces to

$$D'(v - v_0) - D''(v - v_0)\frac{1 - F(v_0)}{f(v_0)} > D'(v^u - v_0) - D''(v^u - v_0)\frac{1 - F(v_0)}{f(v_0)}. \tag{A3.3}$$

Therefore, since $D''(\cdot) > 0$ and $D'''(\cdot) \geq 0$, (A3.3) implies $v(v_0) > v^u(v_0)\ \forall\, v_0 \in [\underline{v}, \overline{v}]$.

Since $v(v_0) > v^u(v_0)\ \forall\, v_0$, $D'(v(v_0) - v_0) > D'(v^u(v_0) - v_0)\ \ \forall\, v_0$. Therefore, it follows immediately from property (iii) in Propositions 1 and 2 that $\pi(v_0|v_0) > \pi^u(v_0|v_0)\ \forall\, v_0 > \underline{v}$. Also, it is apparent from property (i) in Propositions 1 and 2 that $p^u(v_0) > p(v_0) = c\ \forall\, v_0$. Next, recall that

$$\pi^u(v_0|v_0) - \pi(v_0|v_0) + [p^u - c]Q(p^u, v^u) +$$
$$D(v(v_0) - v_0) - D(v^u(v_0) - v_0) - L(v_0) + L^u(v_0). \tag{A3.4}$$

Since the left hand side in (A3.4) is negative and the first three terms on the right hand side are positive, it follows that $L^u(v_0) < L(v_0)$.

Finally, since $p^u(v_0) > p(v_0)$ and $v^u(v_0) < v(v_0)\ \forall\, v_0$, it is immediate that $S(p(v_0), v(v_0)) > S(p^u(v_0), v^u(v_0))\ \ \forall\, v_0 \in [\underline{v}, \overline{v}]$. ■

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