Discussion Paper No. 580

OPTIMAL REGULATORY PRICING UNDER ASYMMETRIC COST INFORMATION

by

Wayne Y. Lee
University of Santa Clara

and

Anjan V. Thakor
Indiana University
Northwestern University

First Draft: August, 1982
Revised: September 1983

We acknowledge with thanks helpful comments received from David Besanko and Vikram Pandit. Responsibility for any remaining errors is solely ours.

Algebraic and Etale K-Theory.

by

William G. Dwyer* and Eric M. Friedlander*

Abstract

This paper addresses the problem of how a regulator, a priori uninformed about a monopolistic firm's variable cost, should set an output price for the firm. The regulator's objective is to maximize a weighted average of consumers and producer surplus. It is shown that the informational asymmetry between the regulator and the firm can be effectively resolved by making price a function of the firm's capital investment. The properties of this price schedule and its implications for the firm's investment decision are explicitly characterized. Some of the intuitive and potentially testable results derived are that if the firm has a higher variable cost, it invests less capital, is awarded a higher price, produces a smaller output and enjoys a lower profit.

Algebraic and Etale K-Theory.

by

William G. Dwyer* and Eric M. Friedlander*

OPTIMAL REGULATORY PRICING UNDER ASYMMETRIC COST INFORMATION

1. Introduction

The optimal regulation of natural monopolies involves setting an output price for the regulated firm such that, given factor input prices (operating costs), the firm's production technology and market demand conditions, the firm's privately optimal level of resource use allows it to earn a rate of return consistent with the maximization of a social welfare function.[1] This price setting process is usually complicated by the fact that the regulated firm has better information about its own operating costs than the regulator does. To overcome its informational disadvantage, the regulator could try to estimate these costs from actual and reported costs over some "test period."[2] Unfortunately, historical costs may be poor indicators of actual costs, and reported costs may be exaggerated by the firm to secure higher prices.[3]

Thus, it is useful to develop pricing rules under asymmetric information that are *ex ante* efficient in the sense that they motivate regulated firms to charge economically efficient prices. Our objective in this paper is to develop such a pricing rule in a setting in which the firm knows its own variable cost of production but the regulator does not.

Our research is part of a growing literature on regulatory pricing under asymmetric information.[4] Baumol, Bailey and Willig (1977) and Panzar and Willig (1977) have argued that by permitting the entry of rival firms, regulators may induce firms to implement welfare maximizing prices without knowing their costs, because doing so would constitute a limit pricing strategy for the firms. While this is an interesting hypothesis, its empirical significance remains largely untested. In like vein, Loeb and

Magat (1979) propose giving the firm title to the entire social surplus and allowing it to choose a price (vector) to maximize this surplus. The right to the monopoly franchise can then be auctioned among competing firms to transfer surplus from producers to consumers. But an auction will be ineffective if only one firm can supply the service efficiently.

In contrast, Baron and Myerson (1982) present a framework in which the regulator designs a revelation game that coaxes the firm to report its private information truthfully. Contingent upon the report, the regulator determines: (i) whether to grant the firm a license to operate, as well as (ii) the output price, and (iii) the size of the subsidy to give the firm. There are two difficulties with this approach. First, regulators in many regulated industries do not have the power to grant subsidies. Second, the optimal regulatory policy could involve closing down even a firm that reports truthfully and whose continued operation, from an ex post perspective, could have benefitted the firm as well as consumers. Service disruption through involuntary closure appears to be a somewhat dire consequence with which to "punish" a firm.

Although similar in spirit, our approach differs substantially from these papers. In our framework the firm signals its a priori unknown variable cost to the regulator through its choice of capital investment. [See Spence (1974) for a development of the signalling model.] Specifically, the regulator designs a price schedule in which the output price is a function of the firm's (observable) capital investment. And the price schedule has the following feature: when the firm responds to the price schedule and selects a profit maximizing level of investment, it earns an allowed rate of return no less than its cost of capital and the resulting allocation is such that a weighted average of producer and consumer surplus is maximized. We find a number of striking results.[5] For example, we show that the presence of asymmetric information will allow the firm to earn a rate of return <u>exceeding</u> its cost of capital, but the level of excess profits enjoyed by the firm will decline as its cost efficiency falls (its variable cost per unit increases). Moreover, the optimal regulatory price is shown to be a decreasing function of the firm's capital investment.

Our approach is sufficiently robust to deal with most economically meaningful production and demand functions, and as far as possible the analysis is carried out with general functions. To obtain sharper insights, however, we make specific assumptions about functional forms in certain parts of the analysis. The assumptions are that the production function is Cobb-Douglas and the market demand function for the firm's output is homogeneous (of some arbitrary degree) in price.

What follows is organized in four remaining sections. Section 2 contains the development of the full information case. In Section 3 we discuss and obtain results with the general model under asymmetric information. Functional form restrictions are imposed on the production and demand functions in Section 4 to characterize the optimal pricing policy further. Section 5 concludes.

2. Regulatory Pricing Under Full Information

To provide a perspective for the more complicated but interesting problem of regulatory pricing under asymmetric information, we first analyze the problem under the assumption that the firm and the regulator are symmetrically informed about the cost of the firm's variable input.

Consider a single regulated firm which is a natural monopoly, and assume a single-period certainty world where all capital is raised through equity. Let p denote the regulatory price per unit of service the firm can charge. Assume the market demand function, q(p), is twice continuously differentiable, bounded and monotone decreasing in price. In addition, the firm's production function, f(K,L), is twice continuously differentiable, bounded and strictly quasiconcave in its arguments, where K denotes the firm's dollar investment in capital and L, the number of units of variable input (labor) hired by the firm. For simplicity, let L and K be divisible, continuous and positive variables Let w, a positive scalar, be the wage rate per unit of the variable input, labor. Further, assume that the wage rate w is known to the regulator (we shall relax this assumption in the next section), and the firm's objective is to maximize the present value of its profits, V, net of invested capital.

The firm's profit can be written as

$$\Pi = pq(p) - wL \ , \tag{1}$$

and its discounted present value as

$$V = \Pi/r \tag{2}$$

where the scalar $r \varepsilon (1,\infty)$ denotes the gross riskless rate of interest, If the product (service) market is in Walrasian equilibrium, demand must equal production (supply). So,

$$q(p) = f(K,L) \ , \tag{3}$$

and the implicit function theorem allows us to write the number of units of labor required in terms of demand and capital investment; namely that,

$$L = L(q,K) \ . \tag{4}$$

Hence, given a regulated price p and an investment level K, the net present value of the firm, Ω, is

$$\Omega(K|p) = V(K|p) - K . \tag{5}$$

The firm chooses an optimal investment level K to maximize net present value, Ω. Clearly, the firm will elect to supply service at the regulated price only if Ω is nonnegative at the desired level of investment. Thus, depending upon the rate of return, s, that the regulator wants the firm to earn, a regulated price p(s) must be determined.[6] Assume that the regulator establishes the allowed rate of return on invested capital based upon a maximization of a weighted sum of consumer and producer surplus.

Formally then, the problem can be posed as the firm choosing

$$\hat{K} \text{ to maximize } \Omega(K|\hat{p}), \tag{6}$$

where $\hat{p}$ satisfies $\{\hat{p}\hat{q} - w\hat{L}\}(\hat{K})^{-1} = \hat{s}$, (7)

and $\hat{s} \varepsilon \underset{s\varepsilon[r,S]}{\operatorname{argmax}} \; (1-\mu) \int_{\hat{p}}^{\infty} q(p)dp + \mu(s-r)\hat{K}$. (8)

In (6) - (8) the argument of p(s) has been dropped and we have defined $q(\hat{p}) \equiv \hat{q}$, and $\hat{L} \equiv L(\hat{q},\hat{K})$. The scalar $\mu\varepsilon[0,1]$ is a weighting factor that determines how consumer and producer surplus are jointly maximized; S is some (very large) arbitrary upper bound for allowed rate of return s; and hats denote (optimal) equilibrium values.[7] Observe further that in (8), $(s-r)\hat{K}$ represents producer surplus and $\int_{\hat{p}}^{\infty} q(p)dp$ represents consumer surplus ignoring income effects.[8]

Now, from the first order condition corresponding to (6) we have

$$-\hat{L}_K = r/w, \tag{9}$$

where again for notational ease we have dropped the arguments of the functions being differentiated. But differentiating (3) yields

$$-\hat{L}_K = \hat{f}_K/\hat{f}_L \,, \tag{10}$$

Hence, combining (9) and (10) we see that the marginal rate of factor substitution equals the factor price ratio. This leads us to our first observation.

Proposition 1: Under full information, given any $\hat{p}$, the regulated firm achieves a technologically efficient use of production inputs.

This result is also obtained in Leland [1974] and Baron and Taggart [1980]. The key is that the firm views the output price as beyond its control. Technological efficiency can thus be achieved at any price, as long as it is consistent with the continued existence of the firm. In setting this price, of course, the regulator must ensure that the consequent rate of return earned by the firm meets the regulator's prespecified social welfare objective. The result is, however, crucially dependent on the assumption of equal information by both parties. In the next section we will show that technological efficiency is unattainable under asymmetric information.

Before examining the properties of the optimal pricing policy, it is convenient to establish the following lemma.

LEMMA: Given any $\hat{p}$, the firm's optimal investment satisfies

$$\hat{K}_p = [-\hat{L}_K]^{-1}\,\hat{L}_q\hat{q}_p \tag{11}$$

PROOF: See the Appendix.

A point of interest is an analysis of how the optimal pricing policy changes as the regulator's welfare objective, parameterized by μ, changes. Three cases, $\mu=0$, $\mu=\frac{1}{2}$, and $\mu=1$, will be examined.

Note that the permissible rate of return on invested capital is a solution to (8) and satisfies[9]

$$[-(1-\mu)\hat{q} + \mu(\hat{s}-r)\hat{K}_p]\ \hat{p}_s + \mu\hat{K} = 0 \ . \tag{12}$$

If the regulator wishes to maximize consumer surplus, it will set $\mu=0$. In that case (12) simplifies to

$$-\hat{q}\hat{p}_s = 0 \ . \tag{13}$$

Since $\hat{q}$ is strictly positive everywhere on its domain, it follows that $\hat{p}_s=0$. That is, the regulatory price is <u>independent</u> of s. Therefore, (7) would require that $\hat{s}=r$.

If producer surplus is to be maximized, the regulator will set $\mu=1$. We can then write (12) as

$$[(\hat{s}-r)\hat{K}_p]\ \hat{p}_s + \hat{K} = 0 \ . \tag{14}$$

Totally differentiating (7), using the Lemma, and rearranging, we have[10]

$$\hat{p}_s = \hat{K}[\hat{q} + \hat{q}_p\hat{p}_s - \hat{K}_p\hat{s}]^{-1} \ . \tag{15}$$

Now substituting (9), (11), and (15) in (14), one obtains the optimality condition

$$\hat{q} + \hat{p}\ \hat{q}_p - \hat{L}_q w\hat{q}_p = 0 \ . \tag{16}$$

But (16) is simply the first order condition for an unregulated monopolist maximizing Ω by choosing an optimal price for a fixed level of capital. Thus, the optimal regulated price which maximizes producer surplus is the profit maximizing unregulated monopoly price. Since at this price the firm earns excess profits, it follows that $\hat{s} > r$.

With $\mu=\frac{1}{2}$, (12) can be simplified to $[-\hat{q} + (\hat{s}-r)\hat{K}_p]\hat{p}_s + \hat{K} = 0$. (17)

Substituting (15) in (17) gives

$$\hat{p} = r\hat{K}_p(\hat{q}_p)^{-1} \ . \tag{18}$$

Joining (9) and (11) results in the equation

$$\hat{K}_p = (w/r)\hat{L}_q\hat{q}_p. \tag{19}$$

Finally, substituting (19) in (18) yields

$$p = w\hat{L}_q , \tag{20}$$

which is the usual first best pricing condition, namely that the unit output price equals the marginal cost of producing an additional unit of output. Thus, we have shown the following result to be true. (This result fails to hold once we relax the assumption that information about w is symmetric.)

Proposition 2: If the regulatory objective is to maximize consumer surplus, the firm will be allowed to earn a rate of return equal to its cost of capital, r. If the objective is to maximize producer surplus, the allowed rate of return will be set higher than the cost of capital. And, if equal weight is assigned to consumer and producer surplus, the regulatory price is set equal to the marginal cost of producing an additional unit of output.

A relationship between the regulatory price and the socially optimal rate of return on capital the firm is allowed to earn can be obtained by combining (11) and (14). From (11) we know that $\hat{K}_p<0$. Thus, (14) implies that $\hat{p}_s>0$, since $\hat{s}>r$. Similarly, (17) implies that $\hat{p}_s>0$. These facts lead to the next observation.

Proposition 3: Under perfect information, if the regulator maximizes either an equally weighted sum of producer and consumer surplus, or simply producer surplus, then the regulatory price is an increasing function of the rate of return on capital the regulator allows the firm to earn.

Our interest in this finding lies not so much in the fact that it is (seemingly obviously) true in a world of perfect information, but in the fact that it breaks down when information is asymmetric. More will be said about this in the next section.

To further characterize the optimal pricing and investment policies under full information, we will now utilize the assumptions that the production function is Cobb-Douglas of the form $\tilde{f}(K,L) = L^{\alpha}K^{\beta}$, where $\alpha\varepsilon(0,1)$, $\beta\varepsilon(0,1)$, and the demand for the firm's output is a homogeneous function of price, $q(p) = bp^{-c}$, where $b>0$, $c>1$. With these stipulations, the first order condition corresponding to (6) yields the optimal investment level

$$\hat{K} = [\{w\, q^{1/\alpha}\, \beta\}(\alpha r)^{-1}]^{\alpha/(\alpha+\beta)}. \tag{21}$$

Note that the partial derivative of $\hat{K}$ with respect to w is positive. This implies the economically sensible result that a higher variable cost of labor contributes to a higher investment in capital. The direct substitution effect does not tell us, however, the total impact of the variable labor cost on the level of investment. Knowledge of the total effect is necessary if inferences about the relationship between output and variable costs are to be made.

To investigate this, consider the case where the regulator attaches equal weights to producer and consumer surplus in the social welfare objective. Using (20) in conjunction with (21) gives us the following expression for the optimal investment

$$\hat{K} = B\, w^{\eta_0}\ , \tag{22}$$

where $B \equiv [b^{\eta_1}\, \beta(r\alpha^{\eta_2})^{-1}]^{\eta_3}$ (23)

and $\eta_0 \equiv -(c-1)(\alpha+\beta)[\alpha+c(1-\alpha) - \beta(c-1)]^{-1}$ (24)

$\eta_1 \equiv [\alpha+c(1-\alpha)^2][\alpha\{\alpha+c(1-\alpha)\}]^{-1}$ (25)

$\eta_2 \equiv -\alpha(c-1)[\alpha+c(1-\alpha)]^{-1}$ (26)

$\eta_3 \equiv (\alpha+\beta)[\alpha+c(1-\alpha)][\alpha\{\alpha+c(1-\alpha) - \beta(c-1)\}]^{-1}$. (27)

Differentiating $\hat{K}$ with respect to w now indicates that

$$d\hat{K}/dw = \begin{cases} < 0 & \text{if } c[c-1]^{-1} > \alpha+\beta \\ > 0 & \text{if } c[c-1]^{-1} < \alpha+\beta , \end{cases} \tag{28}$$

Since $c[c-1]^{-1} > 1$, (28) shows that if the production function exhibits decreasing or constant returns to scale, higher variable costs will always depress capital investment levels. However, with increasing returns to scale, the effect will reverse if the demand for the firm's output is very highly elastic in price.

Substituting (22) in (20) results in the following expression for the optimal regulatory price

$$\hat{p} = Dw^{\eta_5} , \tag{29}$$

where $D \equiv [\alpha^{-1} b^{(1-\alpha)\alpha^{-1}} B^{-\beta\alpha^{-1}}]\alpha[\alpha+c(1-\alpha)]^{-1}$, (30)

$\eta_5 \equiv \{\alpha[\eta_6-\beta(c-1)] + \beta(c-1)(\alpha+\beta)\}\{\eta_6[\eta_6-\beta(c-1)]\}^{-1}$, (31)

and $\eta_6 \equiv \alpha + c(1-\alpha)$. (32)

Differentiating $\hat{p}$ with respect to w gives us

$$d\hat{p}/dw = \begin{cases} > 0 & \text{if } c[c-1]^{-1} > \alpha+\beta \\ < 0 & \text{if } c[c-1]^{-1} < \alpha+\beta . \end{cases} \tag{33}$$

Since demand is negatively related to price, and production equals demand in a Walrasian equilibrium, we have the following remark.

Proposition 4: Assume the regulator and the firm are symmetrically informed about the firm's variable cost. Then, for constant and decreasing returns to scale in production, the firm's optimal investment in capital and its total output both decline as its variable cost rises. The regulated price, however, is an increasing function of the firm's variable cost. With increasing returns to scale in production, these results hold for price elasticities of demand below a critical level. But for sufficiently high elasticities, the signs of all the effects are reversed.

These findings will now serve as a useful benchmark with which to assess the import of asymmetric information about the unit variable cost--a task that is taken up in the next section.

3. Second Best Regulatory Pricing

Suppose the regulator's information about the unit variable cost of production, w, for any particular firm is inferior to the firm's knowledge of this cost. In such a setting, the regulatory pricing problem becomes more complex because a "fixed price" policy for a firm is no longer optimal. The problem is particularly severe with only one firm supplying the service. A fixed price based on inadequate information about the unit variable production cost may either lead to socially suboptimal excess rents for the firm, or may result in the firm refusing to provide the service because its rate of return falls short of its cost of capital. Thus, the informational asymmetry must be resolved, and to do this the regulator should adopt a pricing policy that provides the firm an incentive to reveal its private information.

One way to achieve this is to design a regulatory pricing schedule, $p(K|s)$, that depends on the firm's capital investment and is conditional upon a socially optimal "permissible" rate of return, s, for the firm. This schedule must have the following properties.

1) It should be incentive compatible. That is, faced with the schedule the firm has no incentive to "misrepresent" its true cost, w.[11]

2) The schedule should induce the firm to choose an optimal level of investment such that with that investment the firm earns a rate of return at least as great as its cost of capital.[12]

3) The rate of return earned by the firm is such that a weighted average of consumer and producer surplus is maximized.

Formally then, the regulator faces the problem of designing a pricing schedule $p(K|s)$ without any prior knowledge of w, such that when the firm responds to the schedule by choosing its optimal investment level

$$\hat{K} \text{ to maximize } \Omega(K|\hat{p}) \ , \tag{34}$$

the equation

$$\{\hat{p}\,\hat{q} - w\hat{L}\}\, K^{-1} = \hat{s}(K) \text{ holds,} \tag{35}$$

where

$$\hat{s}(K) \ \varepsilon \ \underset{s\varepsilon[r,S]}{\text{argmax}} (1-\mu) \int_{\hat{p}}^{\infty} q(p)dp + \mu(s-r)\hat{K} \ . \tag{36}$$

Note that $\hat{p} \equiv p(\hat{K}|\hat{s})$, $\hat{q} \equiv q(\hat{p})$, and $\hat{L} \equiv L(\hat{q},\hat{K})$.

This formulation has appeal from a descriptive point of view because regulators do set prices based on the firm's capital stock in an attempt to satisfy a rate of return constraint. Furthermore, firms recognize this and choose their capital stocks accordingly. Observe from (36) that the firm chooses K to maximize net present value at a given p. What makes the problem interesting (and challenging) is that p itself is a function of K. The usual "sophistication" requirements in investigations of incentive compatibility such as this dictate that both the regulator and the firm fully take into account these interrelationships and the response of the other party to it.[13]

The first order condition corresponding to (34) is

$$\hat{p}\hat{q}_p\hat{p}_K + \hat{q}\hat{p}_K - w\hat{L}_K - w\hat{L}_q\hat{q}_p\hat{p}_K - r = 0 \; . \tag{37}$$

Substituting (35) in (37) yields

$$r + \{(\hat{p}\hat{q} - \hat{K}\hat{s})(\hat{L})^{-1}\hat{L}_q\hat{q}_p - (\hat{p}\hat{q}_p + \hat{q})\}\hat{p}_K + (\hat{p}\hat{q} - \hat{K}\hat{s})\hat{L}_K(\hat{L})^{-1} = 0. \tag{38}$$

The solution to the above differential equation will be the optimal pricing schedule, $\hat{p}(K)$, which determines the price awarded to the firm contingent on its capital investment. Note that the $\hat{s}$ in (38) is actually a function of K via (36), which asserts that $\hat{s}(K)$ satisfies[14]

$$\mu\;[(\hat{s}(K) - r)\hat{K}_S + \hat{K}] - [1-\mu][\hat{q}(\hat{p}_S + \hat{p}_K\hat{K}_S)] = 0 \; . \tag{39}$$

Thus, under asymmetric information the regulator observes the firm's capital investment and then determines the rate of return $\hat{s}$ and the price $\hat{p}$ to award the firm by utilizing (38) and (39) simultaneously.[15]

Now define

$$M \equiv (1-\mu) \int_{\hat{p}}^{\infty} q(p)d \;\; + \mu(s - r)\;\hat{K} \; .$$

Ignoring the dependence of s on $\hat{K}$, the partial derivative of M with respect to K is

$$M_K = -[1-\mu][\hat{q}\hat{p}_K] + \mu s \; . \tag{40}$$

At this point we do not know the sign of $\hat{p}_K$. Suppose we conjecture that $\hat{p}_K<0$. Then M_K will be positive. This means that if we view M as a function of s conditional on $\hat{K}$, then $M(s|\hat{K}_1) > M(s|\hat{K}_2)\ \forall\ s,\ \hat{K}_1>\hat{K}_2$. Thus, if $\hat{s} \in \operatorname{argmax} M(s|\hat{K})$, then $\hat{s}(\hat{K}_1) > \hat{s}(\hat{K}_2)$. In other words, $\hat{s}_K>0$.

But totally differentiating (35) yields

$$[\hat{p}_K\hat{q} + \hat{p}\hat{q}_p\hat{p}_K - w\hat{L}_q\hat{q}_p\hat{p}_K - w\hat{L}_K - \hat{s} - \hat{s}_K\hat{K}]d\hat{K}/dw = L(\hat{q},\hat{K}) \tag{41}$$

Further substituting (37) in (41) results in

$$d\hat{K}/dw = -L(\hat{q},\hat{K})[\hat{s}-r + \hat{s}_K\hat{K}]^{-1}. \tag{42}$$

Since $\hat{s}_K>0$ and $\hat{s}\geq r$, we have $d\hat{K}/dw<0$.

Now totally differentiating (37) and rearranging, we obtain

$$\begin{aligned}\hat{L}_q\hat{q}\hat{p}_K + \hat{L}_K = - [&w\hat{L}_{qq}(\hat{q}\hat{p}_K)^2 + w\hat{L}_q\hat{q}_{pp}(\hat{p}_K)^2 \\ &+ w\hat{L}_q\hat{q}_p\hat{p}_{KK} - \hat{p}_K\hat{q}_p\hat{p}_K - \hat{p}\hat{q}_{pp}(\hat{p}_K)^2 \\ &- \hat{p}\hat{q}_p\hat{p}_{KK} - \hat{q}_p(\hat{p}_K)^2 - \hat{q}\hat{p}_{KK} \\ &+ w\hat{L}_{KK} + w\hat{L}_{Kq}\hat{q}_p\hat{p}_K]d\hat{K}/dw\ .\end{aligned} \tag{43}$$

But the quantity inside the square brackets on the right hand side (RHS) of (43) is simply $-\Omega_{KK}$. By the second order sufficiency condition for a maximum, $\Omega_{KK}<0$. Also, $d\hat{K}/dw<0$. Thus, it follows that

$$\hat{L}_q\hat{q}_p\hat{p}_K + \hat{L}_K>0.$$

Since $\hat{L}_K = -\hat{f}_K/\hat{f}_L<0$, we must have $\hat{L}_q\hat{q}_p\hat{p}_K>0$. But $\hat{L}_q = 1/\hat{f}_L>0$ and $\hat{q}_p<0$ by assumption. Therefore, $\hat{p}_K<0$, as conjectured.

Now suppose $\hat{p}_K=0$. Then from (40), $M_K>0$, which means that $\hat{s}_K>0$. This implies $d\hat{K}/dw<0$, and repeating the arguments just made we see that $\hat{p}_K<0$. Thus, we have reached a contradiction and p_K cannot be zero. Finally, assume $\hat{p}_K>0$. Then for μ sufficiently close to one, we can see from (40) that M_K will be positive, implying that $\hat{s}_K>0$. This in turn means that $d\hat{K}/dw<0$ and hence $\hat{p}_K<0$. So we encounter a contradiction once more. Therefore, we conclude that $\hat{p}_K<0$. And with $\hat{p}_K<0$, we obtain $d\hat{K}/dw<0$. These two observations are stated as propositions below.

Proposition 5: The optimal regulatory pricing policy under asymmetric information induces the firm to invest more when its variable cost is lower.

Proposition 6: The optimal pricing schedule is such that, in equilibrium, those who display higher investments are granted lower prices.

Proposition 6 is very intuitive. The regulator wants to set a price based on the firm's variable cost, w, but is *a priori* unaware of this cost. Proposition 5 provides a strong indication of how prices should be determined in such a setting, because it asserts that a firm with a high w chooses a low $\hat{K}$. To ensure that the firm is granted a price consistent with its willingness to provide service, the regulator would like to set a high price if the firm has a high w. Since w cannot be directly observed, the regulator awards a high price when the firm displays a low $\hat{K}$, because it knows that the firm in this case is operating with a high w. The attractiveness of this mechanism is that, *in spite of the fact that the firm knows exactly how the regulator will behave*, the equilibrium is informationally consistent and incentive compatible.[16]

In the next section, functional form assumptions are used to obtain a further characterization of the pricing policy. Part of our motivation for doing so stems from the fact that in practice the regulator would have to know (or estimate) the specific forms of the production and demand functions in order to formulate and implement a pricing policy.

4. Further Results on Pricing Under Asymmetric Information

This section is meant to illustrate how the general approach developed in the previous section can be used in practice. In doing so we are also able to generate a number of empirically testable propositions. We assume

$q(p) = bp^{-c}$, with $b>0$, $c>1$, and $f(K,L) = L^{\alpha}K^{\beta}$, with $\alpha\varepsilon(0,1)$ and $\beta\varepsilon(0,1)$.

The assumption that the demand function is homogeneous (of any desired degree) in price seems eminently reasonable. The Cobb-Douglas production function has been used extensively in economic theory, particularly in studies of regulation. [See Galatin (1968) and Courville (1974a).] It has also been subjected to considerable empirical testing. For example, Courville (1974b) tested two general production models (belonging to the Constant Elasticity of Substitution family) against the Cobb-Douglas using a nonlinear technique and found that the Cobb-Douglas could not be rejected.

Further, the functional forms lead to a welcome analytical simplification. The determination of the allowed rate of return, $\hat{s}$, now becoms independent of the firm's capital investment. This assertion is proven below.

Since q is homogeneous of degree -c in price, Euler's theorem permits us to write

$$\hat{q}_p\hat{p} = -c\hat{q} \ . \tag{44}$$

Moreover, because the production function is Cobb-Douglas, we can use (4) to write

$$\hat{q}L_q(\hat{q},\hat{K}) = \gamma L(\hat{q},\hat{K}) \tag{45}$$

$$\hat{K}L_K(\hat{q},\hat{K}) = -\nu L(\hat{q},\hat{K}) \ . \tag{46}$$

Substituting (44), (45), and (46) in (38) yields the differential equation

$$(\zeta_1 b\hat{p}^{1-c} - \zeta_2\hat{K})\hat{p}_K\hat{K} + [\zeta_3 b\hat{p}^{1-c} - \zeta_4\hat{K}]\hat{p} = 0 \ , \tag{47}$$

where $\zeta_1 \equiv 1-c+c\gamma$, $\zeta_2 \equiv c\gamma\hat{s}$, $\zeta_3 \equiv \nu$, and $\zeta_4 \equiv \nu\hat{s}+r$.

The solution to (47) is a power function,

$$\hat{p}(K) = [\hat{\lambda}K]^{(1-c)^{-1}}, \tag{48}$$

where $\hat{\lambda} \equiv (b\theta_2)^{-1}[\theta_1\hat{s}+(1-c)r] = \hat{s}b^{-1} + (b\Theta_2)^{-1}(c-1)(\hat{s}-r)$, (49)

$$\theta_1 \equiv \theta_2 + c-1$$

$$\theta_2 \equiv c\gamma - (c-1)(1+\nu) \ .$$

Now, the mean value theorem asserts that there exists a price, $\bar{p} \in [\hat{p},\infty)$, such that

$$\bar{p}q(\bar{p}) = \int_{\hat{p}}^{\infty} q(p)\, dp \ . \tag{50}$$

Because q(p) is homogeneous of degree -c in p and the optimal price function is given by (48), the function $\bar{p}q(\bar{p})$ is linear in K. Thus, the $\hat{s}$ that satisfies (36) will be independent of the firm's optimal investment, $\hat{K}$.

The implication of this result is that the firm will be allowed to earn the same rate of return regardless of its variable cost.[17] The allowed rate of return is constrained only by the firm's cost of capital. Note, however, that since $\hat{K}$ still varies with w, the firm will earn larger profits if its w is lower.

We now turn our attention to the impact of the regulator's informational handicap on the determination of the allowed rate of return, $\hat{s}$. Since $\hat{s}$ does not depend in $\hat{K}$, (42) becomes

$$d\hat{K}/dw = -(\hat{s}-r)^{-1}\ \hat{L} \ . \tag{51}$$

Observe that $\hat{L}$ is finite and positive for nontrivial solutions. Also note that (51) stipulates a cross-sectional association between $\hat{K}$ and w. It is evident that $\hat{s}$ cannot be set equal to r, or else the derivative $d\hat{K}/dw$ does not exist, and it becomes meaningless to talk about being able to identify the firm's unit variable production cost on the basis of its observable investment level. Further, $\hat{s} < r$ is infeasible because the firm will refuse to provide service. Therefore, the following result has been proved. (In this section we will not keep repeating that the propositions hold for the production and demand functions we have assumed, but it should be understood that they do.)

Proposition 7: With asymmetric information about variable cost, the regulator must allow the firm to earn a rate of return in excess of its cost of capital, regardless of the regulator's social welfare objective.

The significance of this proposition is that, if the regulator wants to use investment-based price regulation to induce a separating equilibrium in which investment levels "convey information," firms must be allowed to earn excess returns.[18] This is in direct contrast to one of the full-information solutions characterized in Proposition 2. This difference between the full information and asymmetric information settings arises because in the latter case, the regulator is compelled to use the promise of superior returns as an instrument to entice the firm to choose an optimal investment level that truly reflects its private knowledge of variable cost. Clearly, how high the allowed return, $\hat{s}$, is set above the firm's cost of capital, r, will depend on the regulator's social welfare objective. Given any weighting preference μ, however, the deviation of the allowed return in this case from the allowed return in the full information case will be a determinant of the welfare loss due to asymmetric information.

We will now explore the relationships between the firm's variable cost, its capital investment, the regulatory price, and aggregate output. Substituting (48) in (51) yields the differential equation

$$(\hat{s}-r)(d\hat{K}/dw) = -\hat{K}^{-\nu}\, b^{\gamma}\, (\hat{\lambda}\hat{K})^{-c\gamma(1-c)^{-1}} \quad . \tag{52}$$

Solving this differential equation provides the following expression for the firm's optimal capital investment

$$\hat{K} = [\hat{\lambda}]^{-c\gamma\theta_2^{-1}}\, [\hat{s}-r]^{(c-1)\theta_2^{-1}}\, [b^{\gamma} w\theta_2 (c-1)^{-1}]^{(1-c)\theta_2^{-1}} \quad . \tag{53}$$

It is apparent that $d\hat{K}/dw < 0$ [which also follows from (51)], and is a verification of Proposition 5.

Similarly, from (48) and (49) we obtain

$$\hat{p}_s = (1-c)^{-1}\, \theta_1\, (b\theta_2)^{-1}\, \hat{\lambda}^{-1}\hat{p} < 0 \tag{54}$$

and $$\hat{p}_K = (1-c)^{-1}\, \hat{p}\hat{K}^{-1} \qquad < 0 \;, \tag{55}$$

a confirmation of Proposition 6. Further, from (54) we have the following observation:

Proposition 8: When there is asymmetric information about variable cost, the regulatory price is a decreasing function of the rate of return on capital the regulator allows the firm to earn.

Comparing this with Proposition 3, we see that the presence of an informational gap between the regulator and the firm causes a complete reversal in the direction of the effect of $\hat{s}$ on p. From (55) it is apparent that $\hat{p}_{KK}>0$, so that varying $\hat{s}$ produces a whole family of decreasing convex curves in the price-capital investment space, with movement in the southwest direction corresponding to higher regulatory rates of return. By contrast, the full information relationship between price and capital investment is represented by horizontal straight lines, with higher lines associated with higher rates of return. These relationships are graphically displayed in Figure 1.

Insert Figure 1

Next, partially differentiating (53) with respect to $\hat{s}$ gives

$$\hat{K}_s = \hat{K}\{(c-1)\ [\theta_2(\hat{s}-r)]^{-1} - c\gamma\theta_1\ (b\hat{\lambda}\theta_2^2)^{-1}\} \ . \tag{56}$$

Substituting (49), (53), (54), (55), and (56) in (39) and simplifying results (after considerable algebra) in the quadratic equation

$$\xi_1\ (\hat{s}-r)^2 + \xi_2\ (\hat{s}-r) + \xi_3 = 0 \ , \tag{57}$$

where $\xi_1 \equiv \theta_1\ (\theta_1 - c\gamma)\ [\mu\theta_2(c-1) + (1-\mu)\theta_1]$,

$$\xi_2 \equiv \mu\theta_1\theta_2^2 r(c-1) + (1-\mu)\theta_1\theta_2 r\ [c-1+\theta_1-c\gamma] \ , \tag{58}$$

and $\xi_3 \equiv (1-\mu)\ (c-1)r^2\theta_2$.

Thus, $\hat{s}$ will be a solution to (57). Note that $\hat{s}$ will be a function of only those parameters known to the regulator. One can therefore substitute for $\hat{s}$ in (49) and subsequently, for $\hat{\lambda}$ in (48), to obtain a price schedule that depends only on K and known constants.

Thus, if a firm has a higher w, it chooses a lower $\hat{K}$, is granted a higher price, and consequently, its equilibrium production level is lower. From Proposition 4 we know that this is exactly what happens under perfect information for constant and decreasing returns to scale in production. Moreover, it is also true for increasing returns to scale as long as $c[c-1]^{-1} > \alpha + \beta$.

Going back to (48) and (49) we can see that for the optimal solution under asymmetric information to be economically meaningful for all $c>1$, we need $\hat{\lambda}>0$. Since $b>0$, $c>1$, and $\hat{s}>r$, it is sufficient to have $\theta_2>0$, which implies that the condition $c[c-1]^{-1} > (1+\nu)\gamma^{-1} \equiv \alpha+\beta$ is satisfied. This means that for parameter values which permit a meaningful solution under asymmetric information, a firm with a higher variable cost makes a lower capital investment, is awarded a higher price, and produces a smaller output, under both symmetric and asymmetric information.

Our final objective is to examine the manner in which the firm's utilization of capital vis-a-vis labor is influenced by the regulator's social welfare objective.

First, we totally differentiate (35) to obtain

$$[(\hat{q}+\hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p)p_K - w\hat{L}_K - \hat{s}]\hat{K}_s - \hat{K} = -[\hat{q}+\hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p]\hat{p}_s \ . \tag{59}$$

Substituting (37) in (59) gives us

$$(\hat{s}-r)\hat{K}_s + \hat{K} = [\hat{q}+\hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p]\hat{p}_s \ . \tag{60}$$

Further, substituting (60) in (39) and rearranging results in

$$\hat{q}+\hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p = \mu^{-1}(1-\mu)\hat{q}\ [1+p_K(\hat{p}_s)^{-1}\ \hat{K}_s\ ] \ . \tag{61}$$

with $\hat{K}_s$ given by (56).

Now rewrite (37) as

$$(\hat{f}_K/\hat{f}_L) = -\hat{L}_K = w^{-1}\{ r-[\hat{q}+\hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p]p_K\} \ . \tag{62}$$

From (56) and (61) we see that if $\mu=1$ (producer surplus maximized), the quantity $\hat{q} + \hat{p}\hat{q}_p - w\hat{L}_q\hat{q}_p = 0$, and thus (62) implies that

$$(\hat{f}_K/\hat{f}_L) = r/w \ .$$

Moreover, it can also be verified that

$$\lim_{\mu\to 0} [\hat{q}+\hat{p}\hat{q}_p-w\hat{L}_q\hat{q}_p] = \hat{K}(\hat{p}_s)^{-1} - (\hat{s}-r)(\hat{p}_K)^{-1} . \tag{63}$$

Since $\hat{p}_K<0$ and the right hand side of (63) is negative (because $c(c-1)^{-1}>\alpha+\beta$), we have $(\hat{f}_K/\hat{f}_L) < r/w$. Thus, there is overinvestment in capital relative to labor, because the strict quasiconcavity of the production function implies that the marginal rate of factor substitution smoothly diminishes as the level of investment K is increased. These ideas are now summarized in our final proposition.

Proposition 9: If the regulator wishes to maximize producer surplus, the firm makes a technologically efficient use of labor and capital. But if consumers surplus is maximized, the firm overinvests in capital relative to labor.

This result may be viewed as the asymmetric information analog of Proposition 1. The finding that there is overinvestment in capital (with $\mu=0$) when capital serves as a "signal" of the firm's unknown variable cost is similar to the conclusions of other asymmetric information models. For instance, Spence (1974) proves that individuals overinvest in education when it functions as a signal of their a priori unknown native abilities.

4. Concluding Remarks

We have demonstrated how a regulator can set prices in an environment plagued by asymmetric information about the monopolistic firm's variable cost. The informational requirements we impose are that the regulator be aware of market demand conditions, the firm's production technology, and its cost of capital, but need have absolutely no prior information about its variable cost.

The optimal regulatory pricing policy we have characterized is ex ante efficient in the sense that no other feasible policy (a policy that yields the firm a return at least equal to its cost of capital) yields a higher value for the regulator's social welfare objective. It is not ex post efficient, however. Once the firm has chosen a capital investment, the regulator can compute its variable cost. Knowing this variable cost, the regulator could possibly adopt many policies that would generate a higher level of social welfare than the ex ante optimal policy and also induce the firm to produce. But if the firm recognizes this possibility, it may not signal truthfully. That is, although the ex ante efficient policy may be dominated ex post, none of these ex post superior policies can do better ex ante.

Although we have examined the case of the regulator not knowing a factor price, it is clear that equivalent results can be obtained if a parameter that enters linearly in the labor requirements function is a priori unknown to the regulator. For example, the production function could be specified as

$$f(K,L) = AL^{\alpha}K^{\beta} ,$$

where the positive constant A can be viewed as a technological efficiency (returns to scale) parameter. One can then assume that the regulator does not know A. In such a setting the form of the results developed in this paper should remain the same. In fact, some may argue that this is a potentially more interesting application than the case of asymmetric cost information, because regulators are perhaps likely to be better informed about factor prices than about the firm's technology.

The principal advantage of our approach is that it is easy to implement, and does not call for sophisticated randomized regulatory auditing strategies or the threat of service disruption. Moreover, many of our results are testable empirically. Our model is, however, cast in a world of certainty and is single-period. Introducing uncertainty, say on the demand side, is unlikely to prove conceptually more challenging or alter the basic theme of the analysis. But it will make the mathematics less tractable. On the other hand, extension of the model to an intertemporal context, with a possibly nonstationary variable cost, could engender a plethora of interesting new issues, some with potentially significant theoretical and practical implications.

FOOTNOTES

1. To this effect, R. S. Bower (1981) of the New York State Public Service Commission states: "The agency objective is to maximize the weighted sum of consumer and producer surplus through time, and the weight accorded producer surplus will be small if it is a state regulatory agency." As shown in the subsequent discussion, if zero weight is given to producer surplus, the consumer maximizing price is that which makes the rate of return of the regulated firm exactly equal to (marginal) cost of its capital. Pricing in this manner so that the firm's allowed rate of return is exactly equal to its cost of capital has been proposed by Leland (1974).

2. Although two types of test years are used--historical and forecast--in practice, historical test periods predominate. In its 1977 West Iowa Telephone Company decision rejecting a forecast test period, the Iowa State Commission stated: "We have always rejected attempts at using projected data in lieu of known and measurable facts. Speculation is the anathema of regulation." (18 PUR 4th 227).

3. In addition to this moral hazard problem, there are serious problems of cost measurement. For example, operating expenses, capital costs, and depreciation over the test period must be associated with the average investment in the test period. Such estimates require recognition that during the test period, plant and equipment may be added to meet augmented demand or to take advantage of operating efficiencies. Further, not all utilities are alike. Telephone and water utilities, which are not covered by the Public Utility Holding Company Act, commonly have nonutility unregulated operations such as merchandising, manufacturing or real estate investment. Others, such as gas and electric, may operate in several states, or may be subject to various state and federal commission jurisdictions. The diversity of interests makes the allocation of joint costs, such as general overhead expenses and capital charges, an extremely difficult task.

4. See, for example, Baron and Besanko (1983), Besanko (1983), and Weitzman (1978).

5. Some of these results require us to make specific assumptions about the functional forms of the production and demand functions.

6. Note that in this model, p is a function of s through the constraint (7).

7. The expression in (8) need not be concave in s. It is, however, continuous. Since a continuous function is being maximized over a compact set, a maximum will exist. If there are multiple maxima, we will pick the one that maximizes consumer surplus.

8. Consumer surplus, the way we have represented it, can also be found in Baron and Myerson (1982), Vogelsang and Finsinger (1979), as well as numerous other papers. To validate it, consider the following argument. Assume that the marginal utility of money income for each household is only a function of income and has constant elasticity. Also, suppose the total expenditure by a household for the service provided by the regulated firm is a very small percentage of total income, and thus the marginal utility of income is not significantly affected by the price charged by the regulated firm. Then, the social welfare derived from the service of the firm can be equated to a weighted sum of the monetary value of the household consumer surplus, weighting by the marginal utility of money income for each household. Since the marginal utility of money income is assumed to be unaffected by the price charged by the regulated firm, consumer surplus can be measured by the expression we have used.

9. To obtain (12), note that the market demand, q(.), and the optimal capital investment, K, are functions of p. Moreover, p itself is a function of the allowed rate of return, s.

10. To get (15) one should express the labor usage L as a function of q and K and remember that both q and K are functions of p, which is, of course, a function of s. The only constants are μ, s and r.

11. A rather subtle point needs to be made here. Although the firm's choice of K conveys information about its w, whatever learning takes place ex post on the regulator's part is redundant. The pricing schedule is ex ante informationally efficient in the sense that the firm's optimizing decision is consistent with the regulator's social welfare objective, and is incentive compatible in the sense that no firm has an incentive to lie by choosing a K that masquerades it as a firm with a different w. Thus, there is no need for the regulator to attempt to actually compute a firm's w after having observed its K.

12. This condition is obviously imposed to insure the provision of service. In many instances, the courts have ruled that certain services, like the provision of heat during winter in the snowbelt areas, are so essential that they cannot be interrupted even if the consumer in question has not paid his bills.

13. The approach taken here is similar to the approach in other self-selection models in which some personal welfare maximizing choice of the informed conveys information about the a priori unknown attribute to the uninformed. For example, in Spence's (1974) model, the education acquired by an individual conveys information about the individual's ex ante unobservable innate ability.

14. Explicitly recognized in (39) is the fact that the optimal investment level chosen by the firm depends on the rate of return, $\hat{s}$, that the regulator permits it to earn.

15. The dependence of $\hat{p}$ on s means that the entire price schedule shifts depending on the allowed rate of return. Note that (39) implies that s depends on μ, which means that $\hat{p}$ depends on μ through its dependence on s.

16. This result should be contrasted with Baron and Taggart's (1980) analysis. They show that the Averch-Johnson (1962) overcapitalization bias would be the outcome of "naive" regulation in which the regulator adjusts prices based on changes in the firm's capital stock. We quote from their paper:

> As long as the regulator follows some predictable price-setting rule such as this, the firm has an incentive to manipulate its capital stock so as to achieve any price consistent with the regulatory constraint..., and thus the decision problem of the firm under naive regulation is identical to that of the firm in the AJ model. (p. 9).

They propose eliminating this "inefficiency" by adopting "sophisticated" regulation in which the output price is based on some ideal capital stock and is not changed even if the firm chooses a capital stock different from the ideal. In their model, however, sophisticated regulation requires the regulator to know as much about the firm's operation as the firm itself.

17. Some may argue that casual empiricism would indicate that not all regulated firms earn the same rate of return <u>ex post</u>. This, however, cannot be a valid basis for challenging our assumption that the <u>allowed</u> rate of return for firms regulated by the <u>same</u> regulatory agency is the same. This is because cross-sectional variations in realized rates of return may simply be due to these firms facing (nonidentical) idiosyncratic risks in a world of uncertainty.

18. There is empirical support for the observation that regulated firms are permitted to earn rates of return in excess of their costs of capital. For instance, Roberts, Maddala and Enholm (1978) report, "...with an embedded cost of capital of 8 percent, the firm...would be granted 8.95 percent." (p. 620).

APPENDIX

Let $\hat{F}$ denote the bordered Hessian of the production function. By the strict quasiconcavity of the production function, $\hat{F} > 0$. Differentiating (10) with respect to K yields

$$\hat{L}_{KK} = (\hat{f}_L)^{-3}\hat{F} \ . \tag{A-1}$$

Since $\hat{f}_L$, $\hat{F}$ 0, (A-1) implies that $\hat{L}_{KK} > 0$.

Now using (3) and the implicit function theorem, we get

$$\hat{K}_L = -\hat{f}_L/\hat{f}_K \ . \tag{A-2}$$

Differentiating (10) with respect to q and using (A-2), one obtains

$$\hat{L}_{Kq} = -\hat{F}\ \hat{L}_q(\hat{f}_K\hat{f}_L{}^2)^{-1} \ . \tag{A-3}$$

Further, differentiating (9) with respect to p (recognizing that the optimal investment, K, is a <u>function</u> of the regulatory price), yields

$$\hat{K}_P = -(\hat{L}_{KK})^{-1}\ \hat{L}_{Kq}\ \hat{q}_p \ . \tag{A-4}$$

Substituting (A-1) and (A-3) into (A-4) and using (10) now leads us to the desired result. □

REFERENCES

1. Averch, H. and Johnson, L., "Behavior of the Firm Under Regulatory Constraint," American Economic Review, 5 (December 1962), pp. 1052-1069.

2. Baron, D. P., "Price Regulation, Quality and Asymmetric Information," American Economic Review, 71 (March 1981), pp. 212-220.

3. Baron, D. P., "Regulatory Strategies Under Asymmetric Information," Research Paper No. 632, Stanford University, (February 1982), forthcoming in Bayesian Models in Economic Theory, M. Boyer and R. Kihlstrom (ed.), North Holland.

4. Baron, D. P. and De Bondt, R. R., "On the Design of Regulatory Price Adjustment Mechanisms," Journal of Economic Theory, 24 (February 1981), pp. 70-94.

5. Baron, D. P., and Holmstrom, B., "The Investment Banking Contract for New Issues Under Asymmetric Information: Delegation and the Incentive Problem," Journal of Finance, 35 (December 1980), pp. 1115-1138.

6. Baron, D. P. and Myerson, R. B., "Regulating a Monopolist with Unknown Costs," Discussion Paper No. 412, Northwestern University, Econometrica (September 1982), pp.

7. Baron, D. P. and Taggart, R. A., Jr., "Regulatory Pricing Procedures and Economic Incentives," in Issues in Public Utility Pricing Regulation, Michael A. Crew (ed.), Lexington Books, Lexington, MA, (1980), pp. 27-49.

8. Baumol, W. J., Bailey, E. E., and Willig, R. D., "Weak Invisible Hand Theorems on Pricing and Entry in a Multiproduct Natural Monopoly," American Economic Review, 67 (June 1977), pp. 350-365.

9. Besanko, D., "Peak Load Pricing Under Asymmetric Information About Costs," unpublished manuscript, Indiana University, November, 1982.

10. Bower, R. S., "Discussion of Robert A. Taggart, Jr.'s 'Rate-of-Return Regulation and Utility Capital Structure Decisions'," Journal of Finance, 36 (May 1981), pp. 397-399.

11. Brennan, M. J. and Schwartz, E. S., "Consistent Regulatory Policy Under Uncertainty," The Bell Journal of Economics 13-2 (Autumn 1982), pp. 506-524.

12. Courville, L., "Regulation and Efficiency in the Electric Utility Industry," Bell Journal of Economics 5 (Spring 1974a), pp. 53-74.

13. Courville, L., "Regulation and Efficiency in the Electric Utility Industry," Ph.D. Dissertation, Carnegie-Mellon University, 1974b.

14. Dasgupta, P. S., Hammond, P. J., and Maskin, E. S., "The Implementation of Social Choice Rules: Some Results on Incentive Compatibility," Review of Economic Studies, 46 (April 1979), pp. 185-216.

15. Gibbard, A., "Manipulation of Voting Schemes: A General Result," Econometrica, 41, (July 1973), pp. 587-602.

16. Harris, M. and Townsend, R. M., "Resource Allocation With Asymmetric Information," Econometrica, 49 (January 1981), pp. 33-64.

17. Leland, H. E., "Regulation of Natural Monopolies and the Fair Rate of Return," The Bell Journal of Economics, 5 (Spring 1974), pp. 3-15.

18. Loeb, M. and Magat, W. A., "A Decentralized Method for Utility Regulation," Journal of Law and Economics, 22 (October 1979), pp. 399-404.

19. Myerson, R. B., "Incentive Compatibility and the Bargaining Problem," Econometrica, 47 (January 1979), pp. 61-74.

20. Myerson, R. B., "Optimal Auction Design," Mathematics of Operations Research, 6 (February 1981), pp. 58-73.

21. Panzar, J. C. and Willig, R. D., "Free Entry and Sustainability of Natural Monopoly," The Bell Journal of Economics, 8 (Spring 1977), pp. 1-22.

22. Roberts, R. B., Maddala, G. S., and Enholm, G., "Determinants of the Requested Rate of Return and the Rate of Return Granted in a Formal Regulatory Process," The Bell Journal of Economics, 9 (Autumn 1978), pp. 611-621.

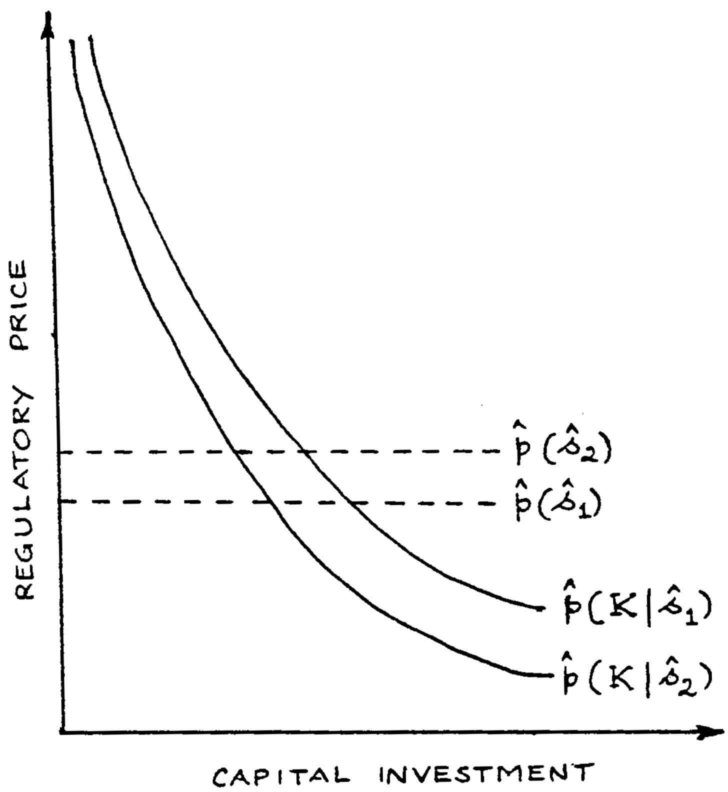
23. Sharkey, W. W., "Suggestions for a Game-Theoretic Approach to Public Utility Pricing and Cost Allocation," The Bell Journal of Economics, 12 (Spring 1981), pp. 144-154.

24. Spence, A. M., "Competitive and Optimal Responses to Signals: Analysis of Efficiency and Distribution," Journal of Economic Theory, 7 (March 1974), pp. 296-332.

25. Vogelsang, I. and Finsinger, J., "A Regulatory Adjustment Process for Optimal Pricing by Multiproduct Firms," The Bell Journal of Economics, 10, (Spring 1979), pp. 157-171.

26. Weitzman, M. L., "Optimal Rewards for Economic Regulation," The American Economic Review, 68 (September 1978), pp. 683-691.

FIGURE 1: REGULATORY PRICE AS FUNCTION OF CAPITAL INVESTMENT



NOTE: $\hat{s}_2 > \hat{s}_1$

DASHED LINES : FULL INFORMATION

FULL LINES : ASYMMETRIC INFORMATION