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ON THE DESIGN OF AUTOMATIC PRICE ADJUSTMENT MECHANISMS

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1. Introduction

During the 1950's and 1960's the regulatory process for electric utilities functioned smoothly as firms were able to earn a satisfactory return while not increasing, and often decreasing, the nominal prices for their output. Increases in factor prices were offset by productivity gains and by the effects of economies of scale realized through growth in demand and through elasticity responses to decreases in real prices. The acceleration of factor price increases that began in the late 1960's, and peaked after the oil price increases in 1973, however, necessitated changes in output prices, and regulatory commissions were forced to deal with a rapidly increasing case load. According to Joskow (1974), "Rapid inflation had quickly changed a very passive and inactive 'rate of return' regulatory process into a very active and continual process of administrative rate of return review. The regulatory process, in terms of both its techniques for adjustments and the staff inputs available to implement the techniques, was completely unsuited for the new economic environment (p. 314)". One feature of electric utility tariffs that expedited rate changes during this period is a fuel adjustment clause (FAC) that permits changes in the average cost of fuels to be passed on directly to consumers without specific commission review. As an indication of the extent to which FAC's are used, NARUC (1977, p. 315) reported that "An FPC survey as of January 1, 1974, showed that 65% of the larger privately-owned utilities had fuel adjustment clauses in their residential schedules, 77% had such clauses in their commercial schedules, and 83% in their industrial schedules."[1] The total documented increases in rates attributable to FAC's for the com-

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price adjustments resulting from a fuel adjustment clause distinguishes it from the administrative rate review process.

To illustrate the nature of the incentive problem, consider the type of "average cost" fuel adjustment clause currently being utilized. If p_o denotes the current price and F_o the quantity of fuel utilized at an output level $Q(p_o)$, the price p adjusted in response to a factor price change from c_o to c is given by the formula

$$p = p_o + (c - c_o) F_o/Q(p_o) . \qquad (1)$$

If the profit of the firm is increasing in price at p_o, a potential moral hazard problem is present to the extent that the firm can affect the fuel usage F_o, and hence the price adjustment, through its choice of technology. A second potential incentive problem centers on the firm's ability to affect the price adjustment through the factor price c of the fuel. A firm may not have an incentive to purchase the least costly fuels, or to convert from one type of fuel to another, if the profit effect of the resulting output price is greater than the additional fuel cost. For example, the New Mexico Public Service Commission (1975, p. 119) has stated

> Under such authorizations, the electric utility can pass on its costs of fuel and purchased power to its customers more or less contemporaneously with experienced increases. However, since it cannot correspondingly increase its service rates to cover increases in depreciation and capital costs per unit of generating capacity or per unit of energy sold, it is disinclined to shift from gas and oil fired generation to coal and nuclear systems. In short, while automatic cost of fuel and purchased power adjustment authorizations are needed to enable the electric utility "to meet all costs of furnishing services", they are likely to operate as a positive disincentive to prepare for and improve the future.

The purpose of this study is to investigate the optimal design of automatic adjustment clauses in light of the potential incentive problems they

The distribution of consumer types will be assumed to be such that a consumer of type $z = 0$ will not purchase at any $p > 0$.[6]

For a two-part price structure with a fixed fee T a consumer will purchase if his surplus is at least as great as T or if

$$\int_{p}^{\infty} Q^{+}(p',z)dp' \geq T. \tag{2}$$

The marginal consumer will be of type $z^{o} = z^{o}(p,T)$ defined by the equality in (2), and z^{o} is a strictly increasing function of p and T, since direct calculation yields $\partial z^{o}/\partial p = Q^{+}(p,z^{o})\partial z^{o}/\partial T > 0$. When a one-part price structure ($T = 0$) is utilized, the marginal consumer z^{o} is the largest z such that $Q^{+}(p,z) = 0$. Aggregate demand $Q(p,z^{o})$ for either price structure is thus given by

$$Q(p,z^{o}) \equiv \int_{z^{o}}^{\bar{z}} Q^{+}(p,z)n(z)dz,$$

and the number N of consumers purchasing from the firm, and hence paying the fixed fee, is $N(z^{o}) = N(z^{o}(p,T))$.

A single-period model will be utilized in which the firm makes its choice of a technology before, and its choice of a fuel after, the change in the factor price and the resulting output price adjustment. The choice of technology may represent the choice among alternative generation technologies or for an existing generation plant may represent, for example, the investment in improved transmission equipment to reduce line losses. The technology will be assumed to involve two inputs, fuel f and capital k, and the cost function will be expressed as $\varphi(Q)M(c,\gamma)$, where $\gamma \equiv f/k$ is the fuel-capital ratio, $\varphi(.)$ is a strictly increasing, continuously differentiable function expressing returns to scale effects, and M is the cost per unit of $\varphi(Q)$. The function M can be expressed as $M(c,\gamma) = cf(\gamma) + rk(\gamma)$, where r is the factor price of of nominal price increases. In the context of the model developed here this policy could be represented by the objective of setting the lowest possible price p subject to the restriction that the owners of the firm are allowed to earn a fair return on their capital. This objective is equivalent to the maximization of consumer surplus, but the objective of maximizing consumer plus producer surplus is more appropriate from a normative point of view. As Bailey (1976, p. 394) however states in rejecting the consumer plus producer surplus objective:

> To suggest to a commission that it might wish to maximize an objective including the benefits to producers is to suggest a sort of behavior that smacks of Stigler's 'capture' theory of regulatory agencies, and is at odds with the 'public-interest' view with which a commission is likely to pride itself [see Posner (1974)]. Thus, my reason for choosing the objective that considered only the position of consumers is that it seemed closer to the stated charter of a regulatory commission.

Since the purpose here is to study adjustment mechanisms in the context of the existing regulatory environment, the regulator will be assumed to have consumer surplus objectives, where the surplus S(p,T) is given by $S(p,t) \equiv \int_p^\infty Q(p',z^o)dp' - TN(z^o)$. The prices to be paid by consumers under an automatic adjustment mechanism are uncertain, however, so expected consumer surplus

$$ES = \int S(p,T)h(c)dc$$

will be utilized. Since the emphasis here is on the design of automatic adjustment mechanisms and on the resulting incentive problems caused by imperfect observability, the regulator and the firm will be assumed to have _ex ante_ asymmetric information regarding the future factor price. That information will be represented by a (differentiable) density function h(c) of the factor price. In the next two sections the fuel supply is assumed to be exogenously determined and the choice of technology is analyzed, while in Section 5 the fuel supply decision itself is treated.

$$S_p = S^*_\rho \pi_p$$

$$S_T = S^*_\rho \pi_T \quad \text{if} \quad T(c) > 0,$$

so the optimality conditions for p(c) and T(c) may be stated as[7]

$$-\frac{S_p}{\pi_p} = \frac{Q}{Q + (p - \varphi' M)Q_1 - \pi_{z^o} n(z^o) \frac{\partial z^o}{\partial p}} = \lambda^* \qquad (7)$$

$$-\frac{S_T}{\pi_T} = \frac{N(z^o)}{N(z^o) - \pi_{z^o} n(z^o) \frac{\partial z^o}{\partial T}} = \lambda^* \text{ if } T > 0, \qquad (8)$$

where $\pi_{z^o} = T + (p - \varphi' M)Q^+$, $Q^+ = Q^+(p, z^o)$, and $\varphi' = \varphi'(Q^+)$. Optimality of the functions $\rho^*(c)$, $p^*(c)$, and $T^*(c)$ characterized by (6), (7), (8) requires that $S + \lambda\pi$ be concave at (p^*, T^*) for all c. The profit function is at least locally optimal if S* concave in ρ at ρ* for all c, which requires that

$$S^*_{\rho\rho} = \frac{\partial}{\partial\rho}\left(\frac{S_p}{\pi_p}\right) < 0 \text{ at } \rho(c) = \rho^*(c), \text{ for all c.} \qquad (9)$$

Consequently, if the ratio of marginal consumer surplus to marginal profit is decreasing with <u>ex post</u> profit, ρ* yields a local optimum. These conditions will be assumed to be satisfied.

The conditions in (6), (7), and (8) characterize the Pareto optimal sharing of the risk resulting from the uncertain factor price and indicate that it is optimal for both parties to bear a portion of that risk. Since an increase in expected profit reduces expected consumer surplus, $\lambda^* > 0$ and (5) indicates that at ρ* an increase in expected profit reduces expected consumer surplus. This implies from (7) that with the optimal unit price function p*, marginal profit π_p is positive, so regulation is effective in maintaining price below the level that the firm would set for the given γ. A similar result follows from (8) if T* > 0. These conclusions are stated as

The first-best price functions depend on the factor price c, and the following proposition establishes that when a one-part structure is utilized a higher factor price results in a higher output price.

Proposition 3: The first-best, one-part price function $p^*(c)$ is a strictly increasing function of the factor price c.

Proof: Differentiation of (10) with $Q^+ = 0$ yields

$$\frac{dp^*}{dc} = \lambda^* \varphi' Q_1 \frac{\partial M}{\partial c} / B, \qquad (12)$$

where

$$B = -(1 - 2\lambda^*)Q_1 - \lambda(\varphi'' Q_1^2 M + (p^* - \varphi' M)Q_{11})$$

is the second-order condition which has been assumed to be negative. The numerator is negative, so $dp^*/dc > 0$. ∎

Although the first-best one-part price function is an increasing function of the factor price, it is not possible to determine in general how the first-best, two-part price functions are related to c for the case of increasing returns to scale.

The form of the first-best profit function $\rho^*(c)$ is important for the fuel supply decision considered in Section 5 and can be determined by multiplying (11) by Q, adding T*N and subtracting φM on both sides, and rearranging to obtain

$$\rho^*(c) = \varphi M(1/\eta - 1) + (1/\lambda^* - 1)Q^2(1 - N(z^o)s(z^o))/Q_1 + T^*N(z^o), \qquad (13)$$

where $\eta \equiv \varphi/(\varphi' Q)$ is the measure of returns to scale. The form of $\rho^*(c)$ is difficult to determine in general, but for constant returns to scale ($\eta = 1$) Proposition 2 implies that $\rho^*(c) = 0$ for all c. With a one-part price structure, the derivative of $\rho^*(c)$ is

The first-best adjustment formulae can be implemented if the factor price c and the firm's choice of technology γ can be observed *ex post*. Since there may be costs associated with monitoring γ, it is natural to ask if there are any potential gains to that monitoring when the factor price itself can be observed. Given any price functions specified by the regulator, the firm will maximize its expected profit, but if the price functions depend only on c, it is clear that the firm will choose the γ that minimizes its expected cost, and hence given $p^*(c)$ and $T^*(c)$ will choose γ^*. Consequently, when the factor price can be observed, there are no gains to monitoring the technology decisions of the firm. The observation of the factor price itself may not be possible, however, without significant expenditures by the regulator. For example, to observe c the regulator may have to audit the accounts of the firm to determine the factor price that actually occurred. Furthermore, if the source of information for a regulator is the accounting records of the firm, data are only available on the fuel supply sources actually used and not on those supplies that were available to but not purchased by the firm.

Corresponding to this case, the regulator will be assumed to only be able to observe *ex post* the "unit" cost $M(c,\gamma)$ and thus must utilize functions $p(M)$ and $T(M)$. This case is of particular interest because the adjustment formula in (1) can be shown to be of this form.
Consider a one-part price structure of the form $p(M) = a + bM$. If $M_o = M(c_o,\gamma)$ represents the initial unit cost before the factor price change, let $a = -bM_o + p_o$ and $b = \varphi(Q(p_o))/Q(p_o)$ where p_o is the initial output price corresponding to M_o. The adjusted price $p(M)$ is then

$$p(M) = p_o + (\varphi(Q(p_o))/Q(p_o))(M - M_o) = p_o + (c - c_o)F_o/Q(p_o),$$

where $F_o = \varphi(Q(p_o))f(\gamma)$, which is the adjustment formula in (1).

$$\max_{\rho(M)} \int S^*(\rho(M),M,\gamma)ydM \tag{15}$$

$$\text{subject to} \int \rho(M)ydM \geq 0 \tag{16}$$

$$\gamma \in \underset{\gamma \in [0,\infty)}{\text{argmax}} \int \rho(M)ydM, \tag{17}$$

where argmax denotes the set of arguments that maximize the succeeding function.

Specification of the conditions characterizing the optimal γ satisfying (17) is difficult because of the complexity of the functions ρ and y. The first-order condition is

$$\int \rho(M)y_\gamma(M)dM = 0, \tag{18}$$

since only the distribution of M depends on γ. The fuel-capital ratio satisfying (18) will be a local optimum if

$$\int \rho(M)y_{\gamma\gamma}(M)dM < 0,$$

but in general it is difficult to determine if for a given $\rho(M)$ the γ satisfying (18) is a global maximum. This issue as well as the existence of a solution to the regulator's program are addressed in Appendix C. If (18) does characterize the firm's choice of technology, replacing (17) with (18) and optimizing pointwise yields the first-order condition for $\rho(M)$.

$$S^*_\rho + \hat{\lambda} + \hat{\psi}\, y_\gamma/y = 0, \tag{19}$$

where $\hat{\lambda}$ and $\hat{\psi}$ are multipliers corresponding to (16) and (18), respectively. The optimal price functions $\hat{p}(M)$ and $\hat{T}(M)$ satisfy the following conditions analogous to (7) and (8)

$$-S_p/\pi_p = \hat{\lambda} + \hat{\psi}y_\gamma/y \tag{20}$$

$$-S_T/\pi_T = \hat{\lambda} + \hat{\psi}y_\gamma/y \quad \text{if} \quad \hat{T} > 0. \tag{21}$$

$$\int S^* y_\gamma dM + \hat{\psi} \int \rho(M) y_{\gamma\gamma} dM = 0 \ .$$

The last term is $\hat{\psi}$ multiplied by the second-order condition for γ which is negative since $\hat{\gamma}$ is optimal. $\blacksquare$

The term $\int S^* y_\gamma dM$ represents the regulator's <u>ex ante</u> preference for a variation in γ with a negative (positive) sign indicating that the regulator prefers a fuel-capital ratio that is lower (higher) than that chosen by the firm. The multiplier $\hat{\psi}$ is thus negative (positive).

To further investigate the optimality of the price functions $\hat{p}(M)$ and $\hat{T}(M)$ characterized by (20) and (21), note that the sign of $S_\rho^* = S_p/\pi_p$ is the opposite of the sign of $(\hat{\lambda} + \hat{\psi} y_\gamma / y)$. Since $S_p = -Q$, $(\hat{\lambda} + \hat{\psi} y_\gamma / y) < 0$ implies that the price p satisfying (20) is such that $\pi_p < 0$ and similarly $\pi_T < 0$ if $T > 0$ satisfies (21). In this case a decrease in p (or T) would increase both profit and consumer surplus until the point at which $\pi_p = 0$.[10] The second-best price adjustment formulae thus satisfy (20) and (21) if $\hat{\lambda} + \hat{\psi} y_\gamma / y \geq 0$, and if $\hat{\lambda} + \hat{\psi} y_\gamma / y < 0$, the optimal prices are such that $\pi_p = 0$ and $\pi_T = 0$. In the second-best solution marginal profit is thus nonnegative which is the counterpart of Proposition 1.

When a two-part tariff is optimal, an expression analogous to (11) results

$$\hat{p}[1 + (1 - \frac{1}{\hat{\lambda} + \hat{\psi} y_\gamma / y})(\frac{1 - N(z^o)s(z^o)}{\varepsilon})] = \varphi' M \ . \qquad (22)$$

The characterization of the second-best pricing policy is less conclusive than that in Proposition 2 for the first-best policy, since the term $(\hat{\lambda} + \hat{\psi} y_\gamma / y)$ depends on M and cannot be related to a returns to scale measure. The following characterization which follows directly from (21) and (22) can be given, however.

when $\hat{\psi} < (>) 0$, since regulation is effective ($\pi_p > 0$) when $\hat{\lambda} + \hat{\psi} y_\gamma / y > 0$.[11]

When only the cost M is observable, a second-best solution results, and in this case there is an opportunity to obtain Pareto superior adjustment formulae by basing those functions on other information that the regulator may obtain. For example, an electric utility must make decisions regarding alternative generation technologies, technologies for transmission and distribution, maintenance and servicing policies, employment of labor of various skills, etc., and the regulator is unlikely to be able to observe all of these decisions. When a regulator cannot monitor all of the components of the technology decision, there may be data collection activities that can provide useful information. For example, accounting data can provide information regarding fuel inputs and their costs, engineering studies can be conducted regarding line losses, heat rates, etc., and econometric studies can provide data on input decisions and their efficiency. Similarly, information could be obtained regarding factor prices of fuel, the sulfur content of alternative fuel supplies, transportation costs, etc.

Holmström (1978) has shown that if information represented by the realization ω of a random variable is such that $y_\gamma(M,\omega;\gamma)/y(M,\omega;\gamma)$ depends on ω, where $y(M,\omega;\gamma)$ is the joint density of M and ω, then the second-best price functions should depend on ω as well as on M. Adjustment mechanisms would thus be expected to depend on information regarding the firm and its economic environment in addition to incurred cost data. This information is, however, rarely costless, so the gains from the information must be compared with the associated costs. While the optimal information acquisition decision will not be investigated here, this analysis does provide a justification for the data collection activities of a regulatory commission. These issues will be considered in more detail in the final section.

through accounting reports. In order to provide a comparison with the first-best policy, the regulator will be assumed to observe the incurred unit fuel cost and not the factor prices of all potential supplies. In order to focus on the fuel mix decision, the fuel-capital ratio will be assumed to be fixed, and only a one-part price structure will be considered.

To represent the fuel mix decision in a simple manner, the firm will be assumed to have a choice between two fuel sources, the first with uncertain factor price c and the second with a certain factor price c^+. The fuel decision will be assumed to be made on an *ex post* basis after the realization of c which corresponds to the use of short-term supply contracts or to spot purchases. The first fuel is taken to be the current supply source, so switching to the second fuel may involve conversion costs. The resulting unit cost of fuel will be denoted by $C(c,c^+,\delta)$ where $\delta \in [0,1]$ denotes the fuel mix. Purchase of only the first fuel will be represented by $\delta = 1$, so $C(c,c^+,1) = c$. Partial conversion to the second fuel is denoted by $\delta \in (0,1)$ with $\delta = 0$ indicating complete conversion. The unit cost function will be assumed to be strictly convex in δ representing costs of conversion that increase at an increasing rate and to be strictly increasing in c for $\delta \in (0,1]$.

Since the fuel supply decision is made *ex post*, the efficient fuel supply minimizes the unit fuel cost C. Because of the observability problem, however, a profit-maximizing firm may have an incentive to purchase fuel inefficiently if its *ex post* profit $\rho(C)$ will be enhanced. If $\rho(C)$ is nonincreasing in C, the firm will not have an incentive to purchase an inefficient fuel mix, but otherwise an incentive for inefficiency is present. Consequently, the first-best profit function $\rho^*(C)$ given in (15) can be utilized when it is nonincreasing which includes the cases of constant returns to scale and constant price elasticity with a homogenous production function.

When the first-best profit function is increasing on some interval,

FIGURE 1

The First-Best Profit Function

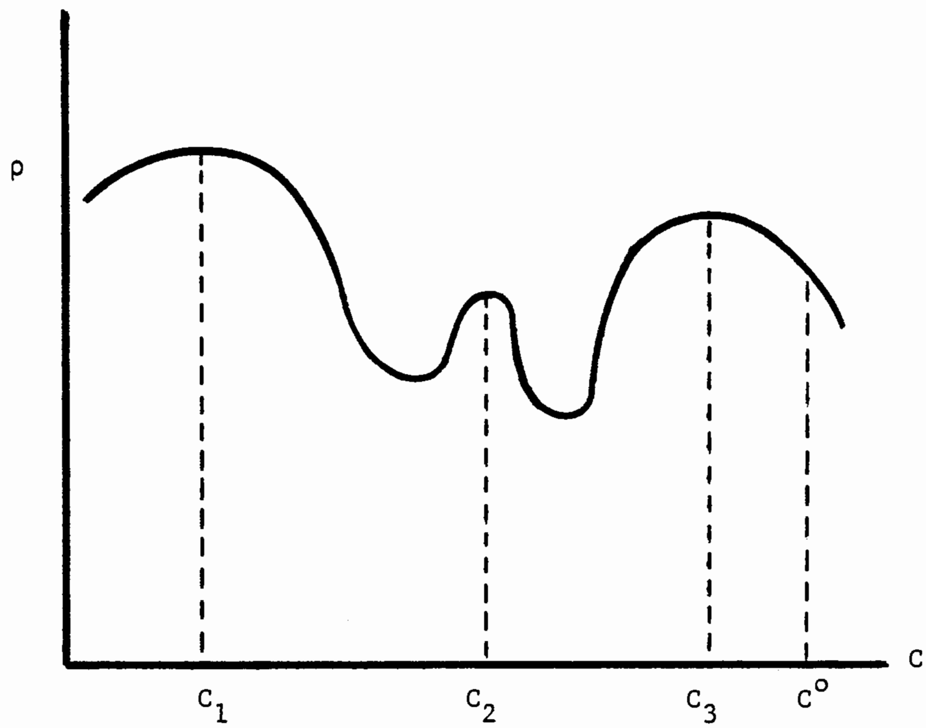
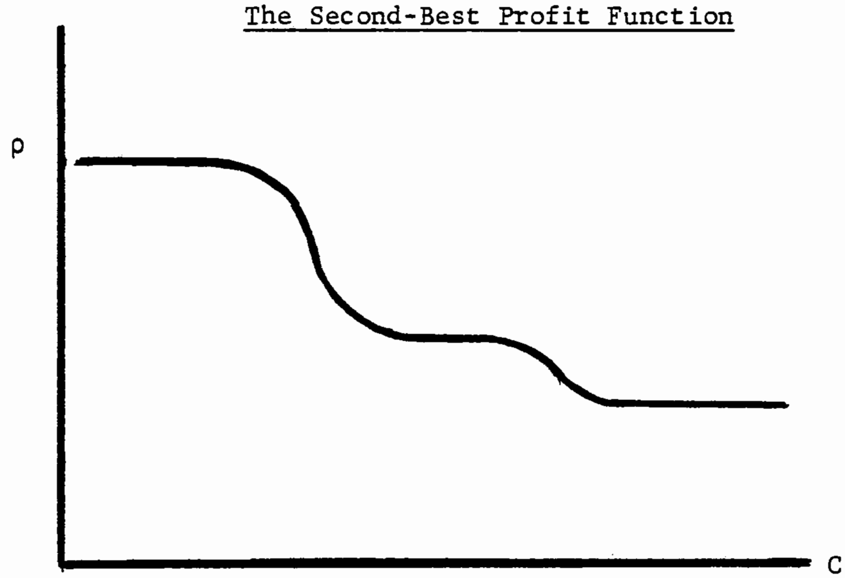


FIGURE 2

The Second-Best Profit Function



Proof: Viewing (23) as a control problem with $\rho(C)$ the state variable and $\rho'(C)$ the control, the necessary conditions may be written as

$$\bar{\xi}'(C) = -(S^*_\rho + \bar{\lambda})v(C) \tag{23}$$

$$\bar{\xi}(C)\bar{\rho}'(C) = 0,$$

where $\bar{\xi}(C)$ is the multiplier associated with the constraint $\rho'(C) \leq 0$. Consequently, $\bar{\rho}'(C) < 0$ on an open interval implies $\bar{\xi}(C) = 0$ and $\bar{\xi}'(C) = 0$, so (23) reduces to (6), which implies (7), on that interval. If $\bar{\xi}(C) > 0$ on an open interval, $\bar{\rho}'(C) = 0$ and $\bar{\rho}(C)$ is a constant $\bar{\rho}$. Then, evaluating $S_p = S^*_\rho \pi_p$ implies the desired result. ■

The profit function $\bar{\rho}(C)$ characterized in Proposition 6 is illustrated by the dotted line in Figure 1. The losses from the first-best optimum result both because $\bar{\rho}(C)$ is not permitted to increase and because $\bar{\rho}(C) > \rho^*(C)$, at least on some interval, in order to compensate the firm for reduced profits on intervals such that $\rho^{*\prime}(C) > 0$.

6. Discussion

While there is no conclusive evidence that automatic adjustment mechanisms are preferable to administrative rate review procedures, their widespread use in the electric utility industry indicates that such mechanisms have certain perceived advantages in terms of matching revenues and costs, in lessening the deterioration of earnings, and in risk sharing. If such mechanisms are to be employed, the first-best formulae involve gains to risk sharing resulting from deivating from average cost pricing (except, of course, for the case of constant returns to scale). When observability is incomplete, however, the predictability of the price changes under automatic adjustment mechanisms can pose incentive problems that re-

The potential incentive to bias the choice of technology when an automatic adjustment mechanism is employed provides a justification for a commission's function of certification of investments. This, of course, requires a significant expenditure to develop the technical expertise necessary to be able to evaluate investment alternatives, but some staff capabilities in this area are likely to be warranted. The commission could additionally conduct cross-sectional studies of electric utilities to compare performance of a particular firm with that of others facing similar conditions. When such monitoring provides informative data regarding the firm's decisions or factor prices, Pareto superior adjustment mechanisms can in principle be developed.

Appendix B

Characterization of the First-Best Price Formulae

To further characterize the first-best price formulae, rewrite (10) as

$$p^* = \varphi' M + p^*(\frac{1/\lambda^* - 1}{\epsilon})(1 - N(z^o)s(z^o)) \qquad (B1)$$

$$= \frac{\varphi}{Q}M + \varphi M(\frac{1}{\eta} - 1)/Q + p^*(\frac{1/\lambda^* - 1}{\epsilon})(1 - N(z^o)s(z^o)), \qquad (B2)$$

where $\eta \equiv \varphi/(\varphi' Q)$ is the returns to scale measure ($\eta > (=)(<) 1$ indicating increasing (constant) (decreasing) returns). The expression in (B1) gives the deviation from marginal cost ($\varphi' M$) pricing, while the expression in (B2) gives the deviation from average cost pricing. If ex post regulation were utilized, average cost pricing would be required, since a fair-return constraint ($\pi = 0$) would be imposed for all c. With ex ante regulation the regulator is able to take advantage of the opportunity to deviate from average cost pricing and hence to increase expected consumer surplus while still providing the firm with an ex ante fair return.

The deviation from average cost pricing consists of two parts represented by the second and third terms in (B2). The first of those terms represents a divergence from average cost pricing in response to the returns to scale of the firm, while the second term represents a compensating effect whose magnitude depends on the demand function. With increasing returns to scale the term $\varphi M(1/\eta - 1)/Q$ is negative reflecting an adjustment in the direction of marginal cost. The last term in (B1) and (B2) is positive, so the unit price could be above average cost for some c when a two-part pricing structure is utilized. The following table summarizes the characterization of the first-best price functions.

				Deviations from Average Cost	
Returns to Scale	λ^*	$T^*(c)$	$p^* - \varphi' M$	Returns to Scale Effect $\varphi M(1/\eta - 1)/Q$	Demand Effect $\frac{p^*}{\epsilon}(\frac{1}{\lambda^*} - 1)(1 - Ns)$
$\eta > 1$	> 1	+	+	-	+
$\eta = 1$	$= 1$	0	0	0	0
$\eta < 1$	< 1	0	-	+	-

M at γ^* is $[M(\underline{c},\gamma^*),\infty)$. If p_o denotes a low penalty price, the regulator could utilize a price function p(M) of the form

$$p(M) = \begin{cases} p^+(M) & \text{if} \quad M \geq M(\underline{c},\gamma^*) \\ p^o & \text{if} \quad M < M(\underline{c},\gamma^*) \end{cases}$$

Since $M(\underline{c},\gamma^*)$ is presumably decreasing in γ for low factor prices, there is a positive probability that the price p^o would be implemented if the firm were to choose $\gamma \geq \gamma^*$. By choosing p^o sufficiently low, it may be possible to compel the firm to choose a fuel-capital ratio no greater than γ^*. If there is an incentive to choose too great a fuel-capital ratio because of an anticipated increase in the price of fuel, such a penalty will be effective in promoting technical efficiency.

5. This assumption implies that the demand functions for individuals of different types do not cross which eliminates the case of prices below marginal cost when returns to scale are increasing as indicated by Oi and by Ng and Weisser.

6. This assumption permits a simplification of the statement of the results.

7. The derivative of consumer surplus with respect to T is

$$\frac{\partial S}{\partial T} = -N(z^o) + \left(\int_p^\infty Q^+(p', z^o)dp' - T\right) n(z^o) \frac{\partial z^o}{\partial T} \quad .$$

By definition of z^o, the term $\left(\int_p^\infty Q^+(p', z^o)dp' - T\right)$ equals zero.

8. This approach is taken by Mirrlees (1976) and Holmström (1978). For each γ the distribution function $Y(M;\gamma)$ is given by

$$Y(M;\gamma) = H(c(M,\gamma)),$$

where H is the distribution function of c and $c(M,\gamma)$ is obtained by inverting $M = M(c,\gamma)$. The density function $y(M;\gamma)$ is then

$$y(M;\gamma) = \frac{\partial Y(M;\gamma)}{\partial M} = h(c(M,\gamma))\left|\frac{\partial c}{\partial M}\right|.$$

If the density function h(c) is defined on the interval $(\underline{c},\bar{c})$, the density y is defined on $(M(\underline{c},\gamma),M(\bar{c},\gamma))$ and will be assumed to equal zero at its bounds. Additionally, y is assumed to be twice differentiable in γ.

9. This interpretation is developed by Holmström (1978).

10. For a one-part price the second-order condition corresponding to p is

$$-Q_1 + (\hat{\lambda} + \hat{\psi}y_\gamma/y)\pi_{pp} < 0.$$

Concavity of π in p and $\hat{\lambda} + \hat{\psi}y_\gamma/y < 0$ implies that the p satisfying (23) is a local minimum rather than a maximum.

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