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**FUEL COST ADJUSTMENT MECHANISMS AND THE REGULATED
UTILITY FACING UNCERTAIN FUEL PRICES***

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1. INTRODUCTION

The work of Averch and Johnson initiated a period of great interest in examining the effects of the structure of utility regulation upon the input choices made by the affected firms. Since their work, the literature on the "A-J effect" has included refinements and extensions of the A-J model itself, as well as discussion about the underlying concepts of regulation which the A-J model implies. The issues of the structure of regulation and the choices made by the regulated firm remain topical. This paper is within the spirit of that examination but the structure which is to be explored is of relatively recent concern: large increases in the cost of petroleum products have made the fuel cost adjustment mechanism, (FAM) or fuel-cost-pass-through, an important institutional development deserving of our attention. Economic intuition suggests that the fuel adjustment mechanism has a potential to distort input choices of the regulated firm.

The relationship between a fuel adjustment clause and input choice is likely to be sensitive not only to the mechanics of the fuel adjustment clause itself but also to the underlying regulatory process to which it is applied. The question of how regulators really behave is itself a continuing subject for debate

and discussion. And, it goes without saying, actual patterns of behavior may differ from the formula rules of the regulatory process.

This paper examines FAM in two different modes of regulation. The first is based upon Joskow's [1974] model of regulatory behavior. The second is patterned after the process formalized in a California Public Utilities Commission tariff.

The organization of the paper is as follows. Section 2 discusses reasons why this topic is important. Section 3 incorporates a fuel adjustment mechanism into a regulatory model originally used by Burness, Montgomery and Quirk [1977] to examine the "turnkey" era in nuclear power plant construction. Section 4 examines a similar mechanism in a model of regulatory behavior derived from a "real world" fuel adjustment tariff. Section 5 contains a discussion of the multi-period effects of a fuel cost pass through program on regulatory activity, and Section 6 provides some conclusions and interpretations.

The results obtained here may be considered somewhat surprising. In the tradition of Averch and Johnson literature, the paper examines input distortions which may result from this particular institutional innovation. The principal result is for such distortions is clear-cut. Furthermore this potential is evident in both regulatory models. However, in some cases, these biases can not be interpreted directly as leading to a more fuel intensive input mix. And, the results are sensitive to the regulatory model chosen.

2. FUEL COST ADJUSTMENT MECHANISMS IN PERSPECTIVE

After scores of comments upon and refinements of the A-J model, the most telling criticism has been that the institution depicted in A-J structure does not reflect the way the regulatory process really operates. In a 1974 article, Joskow contends that "the evidence presented so far . . . appears to contradict the conception of regulation on which the A-J model is based."

Specifically, in Joskow's regulatory world, utility commissioners tend not to initiate rate of return reviews as long as nominal output prices remain stable. Thus, in periods of decreasing costs, regulated firms will not want regulatory review, as the decreasing costs (relative to the old nominal price) allow the firm to increase its rate of return. On the other hand, regulated firms will initiate regulatory reviews during periods of increasing costs.

The Joskow model is important as an historical description of electric utility regulation in the United States. The 1950s and early 1960s apparently were a period of a regulatory equilibrium. The equilibrium was then subjected to two external shocks: (1) sharply increasing costs for inputs: capital and (especially) fuel; and (2) rising environmental requirements as groups concerned with environmental quality conquered the necessary organization costs and began to influence the electric utility regulatory process.

Against the background of these changes, just as Joskow predicted, the fuel cost adjustment has become an increasingly popular institution among participants in the regulatory process.

Table 1 shows the 43 states which, in one form or another, are permitting electric utilities to utilize a FAM. California is included in this list, and that state's pollution authorities have in the past two years tightened the air pollution regulations on sulfur emissions.

These new air quality standards can be achieved in many ways, but there are two polar choices representing primary reliance on two different factor inputs. Utilities may (1) invest in substantial new capital technology in the form of stack scrubbers; or (2) purchase very clean (low sulfur content) fuel oil, at a price even higher than the already drastically increased price for fuel oil used in areas with more lax environmental standards [FPC, 1977]. There are conflicting estimates of the costs of scrubber technology [Hunter and Helgeson, 1976.], [Leo and Rossoff, 1978].

However, Southern California utilities have, up to this point, relied almost exclusively on the "fuel intensive" approach to meeting the clean air standards.

The motivation for the present research is straightforward: can the existence of the fuel adjustment mechanism be altering the incentives for electric utilities to choose one form of pollution control strategy over another? However, the applications of this question go beyond pollution control in urban areas. If potential distortions are suggested, the FAM may also be affecting choices over new investment in alternative energy sources and over conversion of existing plants from one heat technology to another when, depending

TABLE 1
STATES HAVING FUEL ADJUSTMENT MECHANISMS
FOR ELECTRIC UTILITY RATES

Alabama	Missouri
Arizona	Montana
Arkansas	New Hampshire
*California	New Jersey
*Colorado	New Mexico
Connecticut	*New York
Delaware	**North Carolina
*Florida	North Dakota
Georgia	Ohio
**Hawaii	Oklahoma
Illinois	**Oregon
Indiana	Pennsylvania
Iowa	Rhode Island
Kansas	South Carolina
Kentucky	*South Dakota
Louisiana	Tennessee
Maine	Texas
Maryland	Vermont
Massachusetts	Virginia
Michigan	Wisconsin
**Minnesota	Wyoming
**Mississippi	District of Columbia

Source National Association of Regulatory Utility Commissioners, 1976 Annual Report on Utility and Carrier Regulation. States listed are those denoted by NARVC as having regulatory agencies which "allow periodic adjustments for changes in average cost of fuel." States denoted by "**" are not listed by NARVC as having "automatic adjustment clauses". States denoted by "*" are listed as having "automatic adjustment clauses" but with a NARVC footnote that these states, to varying degrees, reserve to their regulatory agencies some discretion and/or oversight with regards to the "automatic" workings of the mechanism.

on regulatory rules, there are different incentives that apply to different technologies, due to differing degrees of "fuel intensity."

3. A TWO PERIOD MODEL OF FAM BIAS IN A THEORETICAL REGULATORY ENVIRONMENT

Montgomery and Quirk [1977] have developed a simple model that is patterned after Joskow's [1974] observations. This section uses that model to demonstrate that the single institutional change of adding a fuel cost adjustment mechanism can cause different production input incentives when the firm faces uncertainty over the future cost of fuel.¹

This is considered a "Joskow model" because of its underlying conception of the regulatory process. The utility regulators in this model are concerned particularly with both nominal output prices and profits. Rather than constantly monitoring the rate of return, they set a nominal price formula in period zero. They do not subsequently react even if the firm's rate of return rises, as long as the firm continues to set prices by the approved formula. The operative constraint, from the view of both the firm and the regulatory commission, is that the firm must earn nonnegative profits.

We suppose a two-period world. Period zero is history -- it may be thought of as "the previous period." The firm, a regulated monopolist, faces uncertainty in the sense that it does not know the price of fuel in period one, the "next period." The position of the demand curve is the same in both periods. The firm must choose ex ante (that is, before the price of fuel in period one, w , can be observed) a level of capital, K , for period one. After w is realized

the firm chooses an optimal amount of fuel input, L^* , so as to satisfy the common carrier requirement

$$F(K, L^*) \geq Q(P) \quad (3.1)$$

where P is the price of the firm's output in period one. $Q(P)$ is a negatively sloped market demand schedule that is the same in all periods.

The firm cannot freely set the price, P , for period one, but it can adjust P to the extent allowed by a FAM problem.

The foregoing sketches a simple, two stage dynamic programming problem. The firm will choose an ex ante optimal amount of capital, with the assumption that it will choose an optimal amount of fuel ex post.

The regulatory environment for this model may be described by the following assumptions:

Model A

Assumption A.1. The firm is constrained to a common carrier requirement, $Q(P) \leq F(K, L)$.

Assumption A.2. There is no storage available either to the firm or to purchasers.

Assumption A.3. The utility regulators have set a base price in the previous period, P_0 . Either this price remains unchanged $P = P_0$, or the price is allowed to adjust according to fuel adjustment mechanism (FAM).

Assumption A.4. The utility regulators will act in period one to insure that the firm earns nonnegative profits. The firm chooses an ex ante optimal $K = \bar{K}$. Then if the realized value of the cost of fuel, w , is so high that

$$PQ(P) - wL(\bar{K}, Q) - r\bar{K} < 0 \quad (3.3)$$

the utility regulators set P at P' such that

$$P'Q(P') - wL(\bar{K}, Q) - r\bar{K} = 0 \quad (3.4)$$

We will define $\tilde{w}(\bar{K})$ as $\{w \mid PQ(P) - wL - r\bar{K} = 0\}$

Assumption A.5. Demand is inelastic ($-1 < \eta(Q) < 0$).

Assumption A.6. There exists a c.d.f. $\Phi(w)$, for fuel price in period one, and $\Phi(w_0) = 0$ (with certainty, fuel costs will not decrease, so $w \geq w_0$). The firm will be assumed to purchase all inputs in a competitive manner, exhibiting no monopsonistic market influence over input prices.

First, assume that there is no FAM. Since resources are not costless, it will never pay the firm to produce more than the quantity demanded, so we can substitute $Q(P)$ for $F(K, L^*)$ in the profit equation, and rewrite L^* as a function of K and Q ,

$$L^* = L(K, Q)$$

The utility commission has set $P_0 = \bar{P}_0 = \bar{P}$, and hence $Q(\bar{P}) = \bar{Q}$. This allows us to suppress the dependence of $L(\cdot)$ on Q , so that $L^* = L(K)$. In the absence of a FAM the objective for the risk neutral, expected profit maximizing firm is to

$$\begin{aligned} \text{Max}_K E(\pi) = & \int_0^{\tilde{w}(K)} \{\bar{P}\bar{Q} - wL(K) - rK\} d\phi \\ & + \int_{\tilde{w}(K)}^{\infty} \{P'Q(P') - wL(K) - rK\} d\phi \end{aligned} \quad (3.5)$$

subject to $K \geq 0, L \geq 0$.

The second integral is identically zero by definition, so (3.5) reduces to

$$\text{Max}_K E(\pi) = \int_0^{\tilde{w}(K)} \{\bar{P}\bar{Q} - wL(K) - rK\} d\phi \quad (3.6)$$

subject to $K \geq 0, L \geq 0$.

Throughout the remainder of this paper, we will assume that the firm's production function $F(K, L)$ is a well behaved neoclassical function: F is strictly quasiconcave. $F_K > 0, F_L > 0, F_{KL} \geq 0, F_{LL} \leq 0, F_{KK} \leq 0$.

$$F(0, 0) = F(K, 0) = F(0, L) = 0.$$

$$\lim_{K \rightarrow 0} F_K = +\infty \quad \lim_{L \rightarrow 0} F_L = +\infty$$

An optimal solution to (3.6) will always satisfy $K > 0, L > 0$.

Then, the first order conditions for a maximum are

$$\int_0^{\tilde{w}(K)} \{-w \frac{\partial L}{\partial K} - r\} d\phi = 0 \quad (3.7)$$

or

$$\int_0^{\tilde{w}(K)} \{-w \frac{\partial L}{\partial K}\} d\phi = r\phi(\tilde{w}(K)) \quad (3.8)$$

totally differentiating the common carrier constraint, A.1, and rearranging yields

$$-\frac{F_K}{F_L} = \frac{\partial L}{\partial K}$$

and, substituting (3.9) into (3.8)

$$\frac{\int_0^{\tilde{w}(K)} \{w \frac{F_K}{F_L}\} d\phi}{\phi(\tilde{w}(K))} = r \quad (3.9)$$

We can interpret this as saying that the firm sets the capital rental rate equal to the conditional expected value of $w \frac{F_K}{F_L}$, where the conditional expectation over $w \frac{F_K}{F_L}$ is the expected value of $w \frac{F_K}{F_L}$ given that w is less than $w(\tilde{K})$. Of course, in the certainty case, $w = \hat{w}$, $\phi(\hat{w}) = 1$ and the firm sets

$$\frac{F_K}{F_L} = \frac{r}{\hat{w}} \quad (3.10)$$

Now, suppose the regulatory agency allows the firm the use of a FAM.

We consider two types of FAMS.²

$$\text{FAM 1: } P = P_0 + \frac{L_1(w - w_0)}{Q_0} ; \text{ FAM 2: } P = P_0 + \frac{wL_1 - w_0L_0}{Q_0} \quad (3.11)$$

where L_1 is the labor chosen in period 1.

In either case, the firm will seek to maximize

$$\max_K E(\pi) = \int_{w_0}^{\tilde{w}(K)} \{PQ - wL_1 - rK\} d\phi \quad (3.12)$$

Appendix 1, discusses conditions under which a firm, having chosen $K = \bar{K}$, and observed $w = \bar{w}$, can and will choose L_1 equal to L^* satisfying:

$$F(\bar{K}, L^*) = Q \left(P_0 + \frac{L^*(\bar{w} - w_0)}{Q_0} \right)$$

thus defining L^* as $L(w, K)$. Appendix 2, states conditions such that the concept of $\tilde{w}(K)$ remains well defined where, as above, $\tilde{w}(K) = \{w \mid PQ(P) - wL(w, K) - rK = 0\}$.

Each of the two FAM formulas are examined separately.

FAM 1

For FAM 1, the first order conditions are as follows:

$$0 = \int_0^{\tilde{w}(K)} \left\{ (w - w_0) \frac{Q(P)}{Q_0} \frac{\partial L}{\partial K} + \left[P \frac{\partial Q(P)}{\partial P} \frac{(w - w_0)}{Q_0} \frac{\partial L}{\partial K} - w \frac{\partial L}{\partial K} \right] r \right\} d\phi \quad (3.13)$$

$$0 = \int_0^{\tilde{w}(K)} \left\{ -\frac{\partial L}{\partial K} \left[w - \frac{(w - w_0)Q(P)}{Q_0} - P \frac{\partial Q(P)}{\partial P} \frac{(w - w_0)}{Q_0} \right] - r \right\} d\phi \quad (3.14)$$

which simplifies to

$$0 = \int_0^{\tilde{w}(K)} \left\{ -\frac{\partial L}{\partial K} \left[w - \frac{[Q(P) + P \frac{\partial Q(P)}{\partial P}] (w - w_0)}{Q_0} \right] - r \right\} d\phi \quad (3.15)$$

Totally differentiating the common carrier constraint (holding with strict equality)

$$F(K, L(w, K)) = Q \left(P_0 + \frac{L(w, K)(w - w_0)}{Q_0} \right) \quad (3.16)$$

$$F_K + F_L \frac{\partial L}{\partial K} = \frac{\partial Q}{\partial P} \frac{(w - w_0)}{Q_0} \frac{\partial L}{\partial K}$$

which implies that

$$-\frac{\partial L}{\partial K} = \frac{F_K}{F_L - \frac{\partial Q(P)}{\partial P} \frac{(w - w_0)}{Q_0}} \leq \frac{F_K}{F_L} \quad (3.17)$$

So, letting η be the elasticity of demand (3.15) becomes

$$\int_0^{\tilde{w}(K)} \left\{ -\frac{\partial L}{\partial K} \left[w - \frac{Q[1 + \eta](w - w_0)}{Q_0} \right] \right\} d\phi = r\phi(\tilde{w}(K)). \quad (3.18)$$

Since demand is inelastic, as long as $w > w_0$ then

$$w - \frac{Q}{Q_0} [1 + \eta] [w - w_0] < w$$

so that (3.17) and (3.18) can be combined and rewritten as:

$$r < \frac{\int_0^{\tilde{w}(K)} \frac{F_K}{F_L} w \, d\phi}{\Phi(\tilde{w}(K))} \quad (3.19)$$

Therefore it is no longer true that the firm sets the conditional expectation of $\left\{ w \frac{F_K}{F_L} \right\}$ equal to r , except in the degenerate case in which $w = w_0$ with certainty.

FAM 2

Similar calculations for FAM 2 yield first order conditions

$$0 = \int_0^{\tilde{w}(K)} \left\{ - \frac{\partial L}{\partial K} \left[w - \frac{Q[1+\eta]}{Q_0} w \right] - r \right\} d\phi \quad (3.20)$$

where

$$- \frac{\partial L}{\partial K} = \frac{\frac{F_K}{F_L}}{F_L - \frac{\partial Q(P)}{\partial P} \left(\frac{w}{Q_0} \right)} \leq \frac{F_K}{F_L}$$

Rearranging this gives us

$$r < \frac{\int_0^{\tilde{w}(K)} \frac{F_K}{F_L} w \, d\phi}{\Phi(\tilde{w}(K))} \quad (3.21)$$

Again, the firm no longer sets the conditional expectation of $\left\{ w \frac{F_K}{F_L} \right\}$ equal to r , except when $w = w_0$ with certainty.

These conditions can be directly related to the world in which there is no uncertainty over fuel costs. Let $w = \hat{w}$, $\hat{w} > w_0$, with certainty. Then (3.19) and (3.21) become

$$r < \frac{F_K}{F_L} \hat{w} \quad (3.22)$$

or

$$\frac{r}{\hat{w}} < \frac{F_K}{F_L} \quad (3.23)$$

if optimal profits are nonnegative at $\hat{w}$. This clearly diverges from the criterion used by a firm that minimizes the costs of producing the same amount of output which is to set $\frac{r}{\hat{w}} = \frac{F_K}{F_L}$.

With a quasiconcave production function the firm will set

$$\frac{F_K}{F_L} \Big|_{Q; \text{ No FAM}} \leq \frac{F_K}{F_L} \Big|_{Q; \text{ FAM}}$$

Furthermore, if the firm's production function is homothetic, in the case of no uncertainty the capital/fuel ratio for a firm with the FAM will be less than or equal to the capital/fuel ratio for

the firm without the FAM even when the output effects are considered (with the FAM, the utility will, usually, produce a lower output than without. The two exceptions are of course the case of completely inelastic demand, and the case where $w = w_0$).

Unfortunately, the clean cut interpretation above (when there is no uncertainty) does not extend to a world with uncertainty. Suppose that with no FAM, the firm chooses $K = K_1$ and that with a FAM it chooses $K = K_2$. Then, the following obtains:

$$\frac{\int_{w_0}^{\tilde{w}(K_1)} \frac{F_{K_1}}{F_{L_1}} d\phi}{\phi(\tilde{w}(K_1))} \leq \frac{\int_{w_0}^{\tilde{w}(K_2)} \frac{F_{K_2}}{F_{L_2}} d\phi}{\phi(\tilde{w}(K_2))} \quad (3.25)$$

Unless $\tilde{w}(K_1) = \tilde{w}(K_2)$, we cannot directly compare the marginal rates of substitution for any given fuel price, w . One case in which $\tilde{w}(K_1) = \tilde{w}(K_2)$ is the naive regulatory environment in which a regulatory agency intends not to guarantee the zero profit condition. Then, the utilities must maximize expected profits over all possible states of the world. This yields the following inequality

$$\int_{w_0}^{\infty} \left\{ w \left(\frac{F_{K_1}}{F_{L_1}} - \frac{F_{K_2}}{F_{L_2}} \right) \right\} d\phi < 0 \quad (3.25)$$

so that, on a set of fuel prices $S \subseteq [w_0, \infty]$ of positive measure,

$$\left. \frac{F_{K_1}}{F_{L_1}} \right|_w \geq \left. \frac{F_{K_2}}{F_{L_2}} \right|_w \quad \text{for } w \in S. \quad \text{This inequality is strict except in the}$$

degenerate case of $w = w_0$ with certainty. Since it is not, in general true that $w(K_1) = w(K_2)$, I present in Appendix 3 a longer interpretation of the input incentives.

Both FAMs cause a departure from the cost minimizing conditions for a firm with neither FAM nor a zero profit constraint. The cost minimizing problem then becomes

$$\min_K \int_{w_0}^{\infty} (wL + rK) d\phi$$

The first order condition is

$$r = \int_{w_0}^{\infty} \left\{ w \frac{F_K}{F_L} \right\} d\phi$$

4. FAM BIAS IN A FORMAL REGULATORY SETTING

The previous results demonstrate that, in a particular regulatory model, there exists a potential for input bias due to the existence of the fuel cost adjustment mechanism. As was noted, the model was based upon a perception of the way regulators actually behave. This section examines the effects of a particular version of FAM that is embedded in a model based upon how one group of regulators

claim to behave. The source of the conceptualization of this FAM and the regulatory process is of a tariff for the FAM used by a large California electric utility. There are two striking differences between this tariff and the Burness, Montgomery, and Quirk model. First, the FAM operates between formal rate reviews. Second, the mechanism for instantaneous activation of a nonnegative profits provision is not apparent. Because the Model A is easily adapted to remove the profit constraint, the interaction between the fuel adjustment mechanism and the rate of return review is more intriguing. To accomplish requires a multiperiod regulatory model. This model called Model B incorporates the following three concepts:

Model B:

Throughout this section, the conditions that demand is inelastic (A.5), that the firm faces a common carrier constraint (A.1) and that the firm has a well behaved neoclassical production function will be assumed.

Assumption B.2:

A Record Period. At time $t = 0$, a base price, P_0 , for output has been set a priori for the firm. The utility cannot influence the price in the record period, but the decisions it makes will influence allowed prices in future periods.

Assumption B.3:

FAM or Fuel Periods. In periods $1 \dots T-1$, the base price, P_0 , is adjusted according to a fuel cost adjustment formula of the following type

$$P_t = P_0 + \frac{L_0 (w_t - w_0)}{Q_0(P_0)} \quad t = 1, \dots, T-1 \quad (4.1)$$

where L_0 and $Q_0(P_0)$ are the fuel input and quantity demanded respectively, in the record period; w_t is the fuel price in period t .

Assumption B.4:

A Review Period. In period T , the firm has a new price set by the rate of return formula

$$P_T = \frac{w_T L^* + s K_0}{Q^*} \quad (4.2)$$

where s is the allowed rate of return, K_0 is the capital input in the record period, and L^* and Q^* are arbitrary fuel and quantity functions whose form will be chosen under various assumptions in the remainder of this section.

The crucial difference between Models A and B is that now the rate of return and not the zero profit constraint is operative. The firm will always be assumed to face uncertain fuel price in periods $t = 1, 2, \dots, T$ with $w_t \geq w_0$ with certainty.

First, the separate effects of only a fuel adjustment clause and only a rate of review mechanism are each compared with the "institutionless" case (no FAM and no rate review). Then the combined system, incorporating both the fuel adjustment clause and the rate of return review is compared with each.

The following new assumptions will flesh out the model:

Assumption A.6. The firm will be required to choose a single capital level $\bar{K} = K_0 = K_1 = \dots = K_T$.

Assumption A.7. In the introductory exposition, I said that the review period price was assumed to be set as

$$P_T = \frac{W_T L^* + s\bar{K}}{Q^*}$$

The following assumptions are introduced about L^* and Q^* .

$$Q^* = Q(P_{T-1})$$

$$L^* \text{ satisfies } F(\bar{K}, L^*) = Q_{T-1}$$

Heuristically, the regulators go to their most recent past fuel use and output data, but they refuse to accept "goldplated" fuel purchases in period Q_{T-1} into the rate calculations. In periods $t = 1, \dots, T-2$ there is no incentive for the firm to goldplate fuel nor to produce more than the quantity demanded. This assumption makes the same true for period $T-1$.

The task facing the risk neutral firm is to

$$\begin{aligned} \max_{\bar{K}} \quad & P_0 F(\bar{K}, L_0) - w_0 L_0 - r\bar{K} + \sum_{t=1}^{T-1} \lambda^t E_t (P_t F(\bar{K}, L_t) \\ & - w_t L_t - r\bar{K}) + \lambda^T E_T (P_T F(\bar{K}, L_T) - w_T L_T - r\bar{K}) \end{aligned}$$

subject to

$$F(\bar{K}, L_0) \geq Q(\bar{P}_0)$$

$$F(\bar{K}, L_1) \geq Q(P_1)$$

$$\vdots$$

$$F(\bar{K}, L_T) \geq Q(P_T)$$

where $E_j(\cdot)$ is the expectation operator and λ is the discount schedule.

A three-period version of this model will serve to demonstrate the results. Period 0 is the record period, Period 1 is the FAM period, Period 2 is the rate review period. Because resources are costly, the common carrier constraint will hold with strict equality in periods 1 and 2, and we can write $L_j = L(Q_j, \bar{K})$, $j = 1, 2$. Define $\pi_t = (P_t Q_t - w_t L_t - r\bar{K})$, and note that since demand is inelastic, $\frac{\partial \pi_t}{\partial P_t} \geq 0$. The record period optimization problem for the expected income maximizing firm can then be written:

$$\begin{aligned} \max_{K, L_0} \quad & L = \bar{P}_0 F(\bar{K}, L_0) - w_0 L_0 - r\bar{K} + \lambda_1 E_1 (P_1 Q_1(P_1) - w_1 L_1(Q_1, \bar{K}) - r\bar{K}) \\ & + \lambda_2 E_2 (P_2 Q_2(P_2) - w_2 L_2(Q_2, \bar{K}) - r\bar{K}) + \mu (F(\bar{K}, L_0) - Q(\bar{P}_0)). \end{aligned} \quad (4.4)$$

Let us first consider an "institutionless" world in which the firm has fixed $P_0 = \bar{P}_0$, $P_1 = \bar{P}_1$, $P_2 = \bar{P}_2$. The Kuhn Tucker necessary conditions for a maximum are

$$0 = P_0 F_{L_0} - w_0 + \mu F_{L_0} \quad (4.5)$$

$$0 = P_0 F_{\bar{K}} - r + \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial \bar{K}} - r \right) + \lambda_2 E_2 \left(-w_2 \frac{\partial L_2}{\partial \bar{K}} - r \right) + \mu F_{\bar{K}} \quad (4.6)$$

$$0 = (F(\bar{K}, L_0) - Q_0) \mu \quad (4.7)$$

which gives us the result that

$$\left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\text{NO FAM}} = \frac{r - \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial \bar{K}} - r \right) - \lambda_2 E_2 \left(-w_2 \frac{\partial L_2}{\partial \bar{K}} - r \right)}{w_0} \quad (4.8)$$

NO R/R

Now, consider a regulatory environment in which the fuel period output price is adjusted according to a fuel adjustment mechanism, but in which there is no rate of return review.

In this case, the first order conditions reduce to

$$\left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\text{FAM}} = \frac{r - \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial \bar{K}} - r \right) - \lambda_2 E_2 \left(-w_2 \frac{\partial L_2}{\partial \bar{K}} - r \right)}{w_0 - \lambda_1 E_1 \left(\frac{\partial \pi_1}{\partial P_1} \left(\frac{w_1 - w_0}{Q_0} \right) \right)} \quad (4.9)$$

To compare the record period marginal rate of substitution when a FAM is available (4.9) and when neither a FAM nor a rate of return review is utilized (4.8), notice that neither the price of fuel in the record period, w_0 , nor the rental of capital, r , change. The denominator of (4.9) contains an additional non-positive term (4.10).

$$- \lambda_1 E_1 \left(\frac{\partial \pi_1}{\partial P_1} \left(\frac{w_1 - w_0}{Q_0} \right) \right) \quad (4.10)$$

If this term is strictly negative either 1) the record period marginal rate of substitution with a FAM (4.9) is greater than in the institutionless case (4.8)

$$\left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\text{FAM}} > \left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\text{NO FAM NO R/R}}$$

or 2) the numerator of (4.8) is larger than the numerator of (4.9) (or perhaps both). The second possibility reduces to (4.11)

$$\begin{aligned} & \left[\lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{\text{NO FAM NO R/R}} \\ & \leq \left[\lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{\text{FAM}} \end{aligned} \quad (4.11)$$

Inequality (4.11) says that the firm's weighted (by discount schedule) sum of expected $(w \frac{F_{\bar{K}}}{F_L} - r)$ will be greater with FAM. Thinking of

$E_1(\cdot)$ as $\int_{w_0}^{\infty} (\cdot) d\Phi(w_1)$ and $E_2(\cdot)$ as $\int_{w_0}^{\infty} \int_{w_0}^{\infty} (\cdot) d\Phi(w_1) d\Phi(w_2)$. The above would require that

$$\left. \frac{F_K}{F_L} \right|_j \Bigg|_w \begin{matrix} \text{FAM} \\ \text{No FAM} \\ \text{No R/R} \end{matrix} \geq \left. \frac{F_K}{F_L} \right|_j \Bigg|_w \begin{matrix} \text{No FAM} \\ \text{No R/R} \end{matrix}$$

for either $\alpha = 1$ or $j = 2$, over some set of fuel prices of positive measure.

If the production function is homothetic, we get the following stronger Proposition (proof in Appendix 4).

Proposition 1

If expression (4.10) is strictly negative, at least one of the following two statements is true

$$1) \left(\frac{F_K}{F_L} \right)_{\text{FAM}} > \left(\frac{F_K}{F_L} \right)_{\text{NO FAM, NO R/R}}$$

and the firm uses absolutely and relatively more fuel in the record period with a FAM.

$$2) E_1 \left(w_1 \frac{F_K}{F_{L1}} \right)_{\text{FAM}} > E_1 \left(w_1 \frac{F_K}{F_{L1}} \right)_{\text{NO FAM, NO R/R}}$$

This says that with homotheticity, either the period zero use of fuel is greater with FAM, or that over some set of positive measure of period 1 fuel prices

$$\left(\frac{F_K}{F_{L1}} \right) \Bigg|_{w_1}^{\text{FAM}} > \left(\frac{F_K}{F_{L1}} \right) \Bigg|_{w_1}^{\text{NO FAM, NO R/R}}$$

A similar comparison can be made between the record period marginal rate of substitution in the institutionless case (4.8) and in the case in which there is a "rate of return" review in period two (4.12).³

$$\left(\frac{F_K}{F_L} \right)_{\text{R/R}} = \frac{r - \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial K} - r \right) - \lambda_2 E_2 \left(\left(-w_2 \frac{\partial L_2}{\partial K} - r \right) + \frac{\partial \pi_2}{\partial P_2} \frac{\partial P_2}{\partial K} \right)}{w_0} \quad (4.12)$$

In this case, the denominators are the same (w_0). The key term is $\frac{\partial P_2}{\partial K}$ which appears in the numerator of (4.12) but not in the expression for the case in which there is no rate review (4.8). Analytically, the $\frac{\partial P_2}{\partial K}$ expression is

$$\frac{w_2 \frac{\partial L_1}{\partial K} + s}{Q_1}$$

or

$$\frac{-w_2 \frac{F_K}{F_{L1}} + s}{Q_1} \quad (4.11)$$

which may be either positive or negative. This ambiguity of sign stems from the fact that increasing initial capital decreases L_1 the fuel needed in period one. Price in period two is a function both of $\bar{K}$ and of L_1 .

In the case in which $\frac{\partial P_2}{\partial \bar{K}}$ is positive, one obtains a

"pro-capital" bias in the first order conditions analagous to the "pro-fuel" bias found with just a FAM, that is, at least one of the following two conditions is true:

$$(1) \quad \left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{R/R} < \left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\substack{\text{NO FAM} \\ \text{NO R/R}}}$$

$$(2) \quad \left[\lambda_1 E_1 w_1 \left(\frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{\substack{\text{No FAM} \\ \text{No R/R}}} \\ \geq \left[\lambda_1 E_1 w_1 \left(\frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{R/R}$$

If $\frac{\partial P_2}{\partial \bar{K}}$ is negative, the opposite results hold.

Finally, compare the results from the "institutionless", "FAM only" and "rate of return and only" models to a world in which the utility has access both to the FAM and to the rate of return mechanism above. With both a FAM and a rate review, the relevant Kuhn-Tucker necessary conditions for a maximum are:

$$0 = \bar{P}_0 F_{L_0} - w_0 + \lambda_1 E_1 \left(\frac{\partial \pi}{\partial P_1} \left(\frac{w_1 - w_0}{Q_0} \right) \right) + \lambda_2 E_2 \left(\frac{\partial \pi_2}{\partial P_2} \frac{\partial P_2}{\partial L_0} \right) + \mu F_{L_0} \quad (4.13)$$

$$0 = \bar{P}_0 F_{\bar{K}} - r + \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial \bar{K}} - r \right) + \lambda_2 E_2 \left(\frac{\partial \pi_2}{\partial P_2} \frac{\partial P_2}{\partial \bar{K}} - w_2 \frac{\partial L_2}{\partial \bar{K}} - r \right) + \mu F_{\bar{K}} \quad (4.14)$$

$$0 = \mu (F(\bar{K}, L_0) - Q(\bar{P}_0)) \quad (4.15)$$

which gives us the condition that

$$\left(\frac{F_{\bar{K}}}{F_{L_0}} \right)_{\substack{\text{FAM} \\ \text{R/R}}} = \frac{r - \lambda_1 E_1 \left(-w_1 \frac{\partial L_1}{\partial \bar{K}} - r \right) - \lambda_2 E_2 \left(\frac{\partial \pi_2}{\partial P_2} \frac{\partial P_2}{\partial \bar{K}} - w_2 \frac{\partial L_2}{\partial \bar{K}} - r \right)}{w_0 - \lambda_1 E_1 \left(\frac{\partial \pi_1}{\partial P_1} \left(\frac{w_1 - w_0}{Q_0} \right) \right) - \lambda_2 E_2 \left(\frac{\partial \pi_2}{\partial P_2} \left(\frac{\partial P_2}{\partial L_0} \right) \right)} \quad (4.16)$$

Obviously, the difference between the marginal rate of substitution in (4.14) and in the institutionless case (4.8) is ambiguous. However, note that these ambiguities manifest themselves in some subtle ways in addition to the combined effects of independent FAM and rate of return distortions.

1. The term $-\lambda_2 E_2 \left(\frac{\partial \pi_2}{\partial P_2} \left(\frac{\partial P_2}{\partial L_0} \right) \right)$ appears for the first time.

This is a direct interaction term. It simply captures the effect that the FAM allows the firm to affect output in period 1 (the fuel period). This change feeds into

the price in period 2 (the rate of return period) via the rate of return mechanism. The sign of $\frac{\partial P_2}{\partial L_0}$ is ambiguous, because L_0 affects the period 2 price

$$P_2 = \frac{w_2 L_1(Q_1, \bar{K}) + sK}{Q_1}$$

both through the numerator and denominator via Q_1 .

2. The expression for $\frac{\partial P_2}{\partial \bar{K}}$

$$\frac{\partial P_2}{\partial \bar{K}} = \frac{w_2 \frac{\partial L_1(Q_1, \bar{K})}{\partial \bar{K}} + s}{Q_1}$$

depends upon Q_1 , which is adjusted via the fuel adjustment mechanisms.

3. $\frac{\partial \pi_2}{\partial P_2}$ will not, in general, be constant as P_2 varies.

We have seen that P_2 is not independent of variables in the fuel period which are adjusted by a FAM.

The ambiguity of the effect of the joint FAM/Rate of Return model on factor proportions is not surprising. This section has already observed that, under some reasonable conditions, a FAM alone produces a pro-fuel bias, while a rate of return review alone produces a bias favoring capital. It is the synergistic ambiguities

which are perhaps the most surprising and interesting. An important point to note is that, because the interactive effects are of uncertain sign, we cannot guarantee on a priori grounds, that using both a FAM and a rate of return review will produce some "happy medium" in input choice.

5. MULTIPERIOD EFFECTS ON REGULATORY BEHAVIOR

Joskow claims that "the existence of these automatic adjustment clauses enabled most electric utilities to flow through the rapidly increased cost of residual fuel oil resulting from the Arab boycott and increased OPEC prices without the necessity of lengthy formal rate of return review. Without the clauses, many companies in the northeast would have been driven to the brink of bankruptcy if standard review procedures had to be followed." [1974]

To consider Joskow's claim in the context of the models presented here, we observe that there are actually four distinct questions to be asked:

1. If a utility has made a choice of capital prior to, and without the expectation of, a fuel cost adjustment clause, will granting a FAM increase the utility's expected profits?
2. If a utility has made a choice of capital prior to, and without the expectation of, a fuel cost adjustment clause, will granting a FAM always result in higher ex post profits for any given period?

3. If a utility chooses capital with full knowledge about the way in which its FAM will operate, will it have greater expected profits than without the FAM?
4. If a utility chooses capital with full knowledge about the way in which its FAM will operate, will its choice of capital always lead to higher ex post profits in every period?

Consider model A. Suppose that with the FAM the utility chose an amount of capital $\hat{K}$, which is equal to the amount of capital chosen without the FAM, $\hat{K}'$. What is the difference in expected profits?

$$E(\pi)_{\text{No FAM}} = \int_{w_0}^{\tilde{w}(\hat{K}')} \{\bar{P}Q - wL - r\hat{K}'\} d\Phi$$

$$E(\pi)_{\text{FAM}} = \int_{w_0}^{\tilde{w}(\hat{K})} \{PQ(P) - wL - r\hat{K}\} d\Phi.$$

Note that at $\tilde{w}(\hat{K}')$, $\pi_{\text{No FAM}} = 0$, but $\pi_{\text{FAM}} \geq 0$ since demand is inelastic, so $\tilde{w}(\hat{K}) \geq \tilde{w}(\hat{K}')$. Therefore, the difference in expected profits is:

$$E(\pi)_{\text{FAM}} - E(\pi)_{\text{No FAM}} = \int_{w_0}^{\tilde{w}(\hat{K}')} \{\pi_{\text{FAM}} - \pi_{\text{No FAM}}\} d\Phi + \int_{\tilde{w}(\hat{K}')}^{\tilde{w}(\hat{K})} \{\pi_{\text{FAM}}\} d\Phi \quad (5.1)$$

but for any w , $w_0 \leq w \leq \tilde{w}(\hat{K})$, $\left. \frac{\partial \pi}{\partial P} \right|_{K=\hat{K}'} \geq 0$

under an assumption of inelasticity of demand. Therefore both terms in (5.1) are nonnegative, and expected profits, given the same capital choice, are at least as high with the FAM as without. Therefore, we have answered "yes" to questions (1) and (2) (given that $\frac{\partial \pi}{\partial P} > 0$) as the assumption of identical capital choice is equivalent to the idea of adding the FAM after capital choice is made.

Furthermore, since the utility would diverge from $K = \hat{K}'$ only if it led to higher expected profits, we know that the FAM leads to expected profits at least as great as in the absence of fuel cost pass throughs. This answers "yes" to question (3).

The answer to question (4), however, is "in general, no." We can show this with an extreme counterexample. Suppose the utility choice $\hat{K}'$ without a FAM, but $\hat{K}''$ with a FAM, because

$$E(\pi) \Big|_{K=\hat{K}''} > E(\pi) \Big|_{K=\hat{K}'}.$$

Now, let w be realized at $w = w_0$. Without the FAM the utility faces the same price and quantity requirement as with the FAM. The firm may be struck with an ex post inefficient amount of capital, relative to the firm without access to a fuel adjustment mechanism.

Likewise, consider model B. We only have to note that in the record period, the utility may be lowering profits, by an inefficient choice of labor and capital. (This is analogous to

Stewart's observation that, with a fixed coefficient production function, "when the change in factor mix precedes the liberalization of the fuel clause . . . the firm must weigh the additional losses it must sustain during the period preceding the respecification of the fuel clause against the possible gains which can be achieved after the respecification."

This leads directly to an integration of the concepts embodied in Models A and B. In Model A, a review comes automatically, but if and only if the zero profit constraint is binding. In Model B, rate of return review comes at a fixed date, T . Suppose that the firm may choose the time for a rate review with a known two period lag. That is, if at the end of time T the utility asks for a review, it will receive the review in period $T + 2$. Furthermore, let the firm be operating, in the meantime, with a FAM such as in Model B.

$$P_t = P_0 + \frac{L_0(w_t - w_0)}{Q_0}. \quad (5.2)$$

For simplicity, let the rate review in period $T + 2$ depend only on data generated in periods 0 , $T + 1$, and $T + 2$ (so that it is independent of decisions made in periods $1, 2, \dots, T$). Then, in each period $t = 1, 2, \dots, T$

$$E(\pi_t) = E(P_t Q_t - w_t L_t^* - r\bar{K}).$$

Under these assumptions, the firm will, in periods $1, 2, \dots, T$, set the common carrier constraint at strict equality, and $L^* = L(Q_t, \bar{K})$.

Suppose the firm's decision rule is to ask for a rate of return review if actual profits in any period fall below some constant

$$\pi_t < H. \quad (5.3)$$

Suppose further that, in the absence of a FAM, the firm chooses an amount of capital $\bar{K}'$ so that it expects to ask for a review in period T^* . For all periods $t = 1, 2, \dots, T^*$, if demand is inelastic, expected profits

$$E(\pi_t) = E(P_t Q_t - w_t L_t - r\bar{K})$$

will be at least as great if a FAM is in existence and the same amount of capital, $\bar{K}'$ is chosen. Therefore, for the same amount of capital utilized, the firm will expect to go at least as long before asking for a review when it is allowed a FAM.

Furthermore, at $\bar{K} = \bar{K}'$, the same can be said of the ex post decision of the firm: ex post profits will always be at least as great with a FAM as long as demand is inelastic. So, the firm actually will go at least as long between rate reviews. However, when we allow the quantity of capital to diverge between the two circumstances, $\bar{K} \neq \bar{K}'$, the optimal T^* can vary and the caveat of questions (4) above still holds: ex post the firm may find that it has lower profits than with a different capital choice and no FAM, although, of course, the discounted stream of expected profits will be at least as great with a FAM as without.

6. SUMMARY AND CONCLUSIONS

Suspensions that fuel adjustment mechanisms distort input choices are justified. My results agree precisely (in the case of no fuel cost uncertainty) with other results proposing that there will be an incentive for utilities to invest in relatively more fuel intensive technologies than would be employed by a firm producing the same output.

The addition of uncertainty does not eradicate the result that input incentives are altered, however the interpretation of these biases as "pro-fuel" or "anti-fuel" becomes more difficult.

In the "Joskow" model of Section 3, the utilization of the fuel adjustment mechanism will not, in general leave the bankruptcy level of fuel prices unchanged. Furthermore, through the FAM, output produced by the firm is allowed to vary. These bankruptcy and "output" effects make it impossible to compare directly the resulting choice of technology for any realized fuel price level except when the fuel price levels at which the regulators step in are identical.

In the interactive model of Section 4, we saw that acting alone, the fuel period FAM mechanism will yield a "pro-fuel" distortion (again, refer to Appendix 4). When combined with a rate of return review price mechanism, the resulting situation results in a distinct alteration of input incentives viz-à-viz an institutionless world, but the interaction makes it impossible to describe the direction of the biases. I pointed out that there are synergistic effects which are more than simply a combination of the distortions seen when the FAM or rate of return review operates independently.

Thus, electric utility regulators face somewhat of a dilemma: on the one hand, Section 5 of this paper demonstrated that the FAM can play a role in preserving the financial integrity of electric utilities without a massive overburdening of the regulatory process. On the other hand, this is obtained at a cost of inefficiencies in input choices which, in some specific cases, lead to a relatively more fuel intensive technology. In addition, how regulators evaluate the potential that a FAM interacts with the possible "pro-capital" A-J biases, as suggested by Model B remains an open question. One application of the results presented here is to address the questions posed earlier regarding pollution control strategy choice in Southern California. The results presented here indicate that the fuel adjustment clause must be considered as relevant to the decisions of Southern California utilities to rely more on the "fuel intensive" approach to meeting air quality standards.

APPENDIX 1

Since P is a function of L and w , for a given w we can state a derived demand $Q(P(L)) = Q(L)$, with $\frac{\partial Q}{\partial L} = \frac{\partial Q}{\partial P} \frac{\partial P}{\partial L}$. For FAM 1, $\frac{\partial P}{\partial L} = \frac{w - w_0}{a_0}$. For FAM 2, $\frac{\partial P}{\partial L} = \frac{w}{Q_0}$. Since $w \geq w_0$, and $\frac{\partial Q}{\partial P}$, the function has a nonpositive slope.

FIGURE 1-1

Likewise, we can state the production relation $F(\bar{K}, L)$ for a fixed level of $K = \bar{K}$.

FIGURE 1-2

Figure 1-2 depicts diminishing returns to L for fixed K .

$L^* = L(\bar{K}, w)$ will be defined by the intersection of the two curves

FIGURE 1-3

As long as $\lim_{L \rightarrow \infty} F(\bar{K}, L) = +\infty$ we can rule out cases such as

FIGURE 1-4

where no intersection occurs. The proposition to be shown is that the firm never has an incentive to move from L to $\bar{L}$ in Figure 1-5 (the firm must stay "northeast" of $Q(P, L)$) by the common carrier constraint).

FIGURE 1-5

Suppose the firm is at L . To move to $\bar{L}$, the firm must add ΔL fuel, at a cost of $w\Delta L$. The marginal cost of increasing fuel usage is, therefore, w . The marginal revenue gained in FAM 1 is

$$\frac{\partial PQ}{\partial P} \frac{\partial P}{\partial L} = \frac{\partial PQ}{\partial P} \frac{(w - w_0)}{Q_0} = \left(Q + P \frac{\partial Q}{\partial P} \right) \left(\frac{w - w_0}{Q_0} \right) = Q \frac{w - w_0}{Q_0} + P \frac{\partial Q}{\partial P} \left(\frac{w - w_0}{Q_0} \right)$$

The second term $P \frac{\partial Q}{\partial P} \left(\frac{w - w_0}{Q_0} \right)$ is clearly nonpositive, so a necessary condition for increasing fuel to be profitable is that

$$Q \left(\frac{w - w_0}{Q_0} \right) \geq w. \text{ However, since } \frac{\partial Q}{\partial P} < 0, Q < Q_0, \text{ so}$$

$$\frac{Q}{Q_0} (w - w_0) < w - w_0 < w$$

————><————

As long as $w_0 > 0$.

Likewise, for FAM 2, a necessary condition is that

$$\frac{Q}{Q_0} (w) \geq w.$$

A contradiction will obtain if $\frac{\partial Q}{\partial P} < 0$

APPENDIX 2

It is no longer obvious that the function $\tilde{w}(K)$ is well defined. Recall that $\tilde{w}(K)$ (which may be $+\infty$) is the level of fuel prices such that

$$\pi(K, w) < 0 \quad \forall w > \tilde{w}(K)$$

$$\pi(K, w) \geq 0 \quad \forall w \leq \tilde{w}(K)$$

What we need to avoid is a situation such as the following:

with a FAM, $\frac{\partial \pi}{\partial w}$ for any given level of capital can be expressed as

$$\left. \frac{\partial \pi}{\partial w} \right|_{K=\bar{K}} = \frac{\partial R}{\partial P} \left(\frac{\partial P}{\partial L} \frac{\partial L}{\partial w} + \frac{\partial P}{\partial w} \right) - L - w \frac{\partial L}{\partial w}. \quad (\text{A.2-1})$$

First, we must find an expression for $\frac{\partial L}{\partial w}$. To do this, totally differentiate the common carrier constraint

$$F(\bar{K}, L(\bar{K}, w)) = Q(P(w, L(\bar{K}, w))).$$

For FAM 1

$$F_L \frac{\partial L}{\partial w} = \frac{\partial Q}{\partial P} \left[\frac{L}{Q_0} + \frac{w - w_0}{Q_0} \frac{\partial L}{\partial w} \right]$$

so

$$\frac{\partial L}{\partial w} = \frac{\frac{\partial Q}{\partial P} \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w - w_0}{Q_0} \right)}. \quad (\text{A.2-2})$$

For FAM 2

$$F_L \frac{\partial L}{\partial w} = \frac{\partial Q}{\partial P} \left[\frac{L}{Q_0} + \frac{w}{Q_0} \frac{\partial L}{\partial w} \right]$$

so

$$\frac{\partial L}{\partial w} = \frac{\frac{\partial Q}{\partial P} \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}}. \quad (\text{A.2-3})$$

Note that both (A.2-2) and (A.2-3) are nonpositive. Now, for FAM 2, evaluate (A.2-1) using (A.2-3)

$$\left. \frac{\partial \pi}{\partial w} \right|_{K=\bar{K}} = \left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{w}{Q_0} \frac{\frac{\partial Q}{\partial P} L}{Q_0} + \frac{L}{Q_0} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}}$$

which equals

$$\left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{\frac{w}{Q_0} \frac{\partial Q}{\partial P} L + F_L \frac{L}{Q_0} - \frac{L}{Q_0} \frac{\partial Q}{\partial P} \frac{w}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}}$$

or

$$\left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{F_L \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}}$$

then

$$\frac{\left[P \frac{\partial Q}{\partial P} + Q \right] \left[F_L \frac{L}{Q_0} \right] - L F_L + L \frac{\partial Q}{\partial P} \frac{w}{Q_0} - w \frac{\partial Q}{\partial P} \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \frac{w}{Q_0}} \quad (\text{A.2-4})$$

The sign of (A.2-4) will depend on the numerator, which simplifies to

$$\left[P \frac{\partial Q}{\partial P} \right] F_L \frac{L}{Q_0} + F_L L \left[\frac{Q}{Q_0} - 1 \right]. \quad (\text{A.2-5})$$

(A.2-5) is unambiguously nonpositive since $Q \leq Q_0$. Therefore,

$\frac{\partial \pi}{\partial w} \leq 0 \quad \forall w \geq w_0$, and $\tilde{w}(K)$ is well defined for FAM 2.

Next consider FAM 1. Substitute (A.2-2) into (A.2-1) to

get

$$\left. \frac{\partial \pi}{\partial w} \right|_{K=\bar{K}} = \left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{(w-w_0)}{Q_0} \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)} + \frac{L}{Q_0} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)}$$

which equals

$$\left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{\left(\frac{w-w_0}{Q_0} \right) \frac{\partial Q}{\partial P} \frac{L}{Q_0} + \frac{L}{Q_0} F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right) \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)}$$

that is

$$\left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{\frac{L}{Q_0} F_L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)} \right] - L - w \frac{\frac{\partial Q}{\partial P} L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)}$$

Combining terms, we get

$$\frac{\left[P \frac{\partial Q}{\partial P} + Q \right] \left[\frac{L}{Q_0} F_L \right] - L F_L + L \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right) - w \frac{\partial Q}{\partial P} \frac{L}{Q_0}}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w-w_0}{Q_0} \right)} \quad (\text{A.2-6})$$

The sign of (A.2-6) will be determined by the numerator, which simplifies to

$$P \frac{\partial Q}{\partial P} \frac{L}{Q_0} F_L + L F_L \left[\frac{Q}{Q_0} - 1 \right] - \frac{w_0}{Q_0} \frac{\partial Q}{\partial P}$$

$$\text{or} \quad \frac{L}{Q_0} \frac{\partial Q}{\partial P} (P F_L - w_0) + L F_L \left(\frac{Q}{Q_0} - 1 \right) \quad (\text{A.2-7})$$

The second term is clearly nonpositive. The first term, however, may be positive or negative. Therefore, we cannot rule out a priori that $\tilde{w}(K)$ is not well defined. However, we need not resort only to assuming the designed result for the entire range of fuel prices; we can work with a slightly weaker set of assumptions. Note that since

$$\frac{\partial P}{\partial w} = \frac{\frac{L}{Q_0} F_L}{F_L - \frac{\partial Q}{\partial P} \left(\frac{w - w_0}{Q_0} \right)} > 0$$

$$\frac{\partial [P F_L]}{\partial w} > 0 \quad \text{if } F_{LL} \leq 0. \quad (\text{A.2-8})$$

Then we assume that

1. Either (a) $\exists$ some w^* such that

$$P F_L \Big|_{w^*} = w_0$$

or (b)

$$P F_L \Big|_{w_0} > w_0$$

2. If not (1) (b) above, then profits are nonnegative

$$\forall w \quad w_0 \leq w < w^*.$$

If $\tilde{w}(K)$ is not well defined for FAM 1, we must then replace the concept of integrating from w_0 to $\tilde{w}(K)$ with $\int_E \pi(w) d\phi(w)$ where E is the set of fuel prices for which the firm earns nonnegative profits, and E is assumed to have positive measure.

APPENDIX 3

Quantity or output effects can complicate the analysis of input choice by regulated firms. This model is no exception. In fact, the quantity effects are especially bothersome since they occur after the random variable is observed. For each different value of w , the FAM utility will be operating at a different level of output.

As noted in the text, the other complicating factor with this model is what can be called the bankruptcy effect. The term $\tilde{w}(k)$ indicates the level of fuel wits at which the firm will be just earning zero profits. (Appendix 2 discusses the conditions under which $\tilde{w}(K)$ is well defined). The problem which arises in first order conditions is that $\tilde{w}(K_2)$ will in general differ from $\tilde{w}(K_1)$.

To demonstrate a little more simply the ambiguities which are caused, consider the following special case. There are only two states of the world

$w_1 > w_0$ occurs with probability ρ

$w_2 > w_1$ occurs with probability $1 - \rho$

Furthermore, suppose the following are true

$w_2 > \tilde{w}(K_1) > w_1 > w_0$

$\tilde{w}(K_2) > w_2$

So that without a FAM, the firm earns positive profit at w_1 , but is bankrupt at w_2 . With FAM, the profit maximizing choice leaves the firm solvent in both cases.

Then, inequality 3.25 becomes

$$w_1 \frac{F_{K_1}}{F_L(K_1, w_1)} \leq \rho w_1 \frac{F_{K_2}}{F_L(K_2, w_1)} + (1 - \rho) w_2 \frac{F_{K_2}}{F_L(K_2, w_2)} \quad (A.3-1)$$

or

$$\frac{F_{K_1}}{F_L(K_1, w_1)} \leq \rho \frac{F_{K_2}}{F_L(K_2, w_1)} + (1 - \rho) \frac{F_{K_2}}{F_L(K_2, w_2)} + (1 - \rho) \left(\frac{w_2 - w_1}{w_1} \right) \frac{F_{K_2}}{F_L(K_2, w_2)} \quad (A.3-2)$$

Because the third term on the right hand side of (A.3-2) is positive, the inequality gives us no information about the relative magnitudes of the marginal rates of technical substitution. Furthermore, the firm is producing a different quantity of output at each of the three states (no FAM with w_0 , FAM with w_1 , and FAM with w_2). Only as

$$\rho = 1 \text{ does the inequality } \text{sign} \frac{F_{K_2}}{F_L(K_2, w_1)} - \frac{F_{K_1}}{F_L(K_1, w_1)} .$$

There is one construct in which one can control for the output and bankruptcy effects. I will call this the output response identical (ORI) firm. In our model, an ORI firm with respect to the FAM utility is any firm which produces the same output quantity given the same realization of the random variable, w .

Consider the firm which is regulated to be ORI with respect to the FAM utility. Call this firm ORI_2 . ORI_2 is given a price function

$$P_{ORI_2} : w \rightarrow R$$

with the following properties

- i) P_{ORI_2} is independent of any action taken by the ORI_2 firm.
- ii) $\forall w \ w_0 < w < \tilde{w}(K_2)$

$$P_{ORI_2} = P_{FAM}$$

hence $Q(P_{ORI_2}) = Q(P_{FAM})$

Consider the conditions for expected profit maximization for the ORI_2 firm restricted to the range w_0 to $\tilde{w}(K_2)$

$$\text{Max}_{K_3} \int_0^{\tilde{w}(K_2)} \{PQ - wL_3 - rK_3\} d\phi \quad (A.3-3)$$

The first order condition is

$$r = \frac{\int_0^{\tilde{w}(K_2)} \left\{ w \frac{\partial L_3}{\partial K_3} \right\} d\phi}{\Phi \tilde{w}(K_2)} = \frac{\int_0^{\tilde{w}(K_2)} \left\{ w \frac{F_{K_3}}{F_{L_3}} \right\} d\phi}{\Phi \tilde{w}(K_2)} \quad (A.3-4)$$

Which is precisely the condition for minimizing the expected costs in the range w_0 to $\tilde{w}(K_2)$ for an ORI_2 firm.

Thus, we can compare (A-3.4) to (3.19) to see that the FAM utility departs from the input choices which would minimize the cost of the particular output schedule the firm has chosen restricted the range w_0 to $\tilde{w}(K_2)$. Furthermore, over some interval of positive measure of fuel prices, this divergence entails an inefficiently high

$\frac{F_K}{F_L}$ and hence an inefficiently fuel intensive input mix.

APPENDIX 4

(Proof of Proposition 1)

Lemma 1. With no FAM and no R/R, the firm will never produce more than demand in the record period.

Proof of Lemma 1. Suppose the firm chose $\bar{K}'$ and L' such that

$F(\bar{K}', L') > Q_0$. By reducing fuel by ΔL , the firm loses nothing in periods 1 and 2 and gains $w_0 \Delta L$ in period 0.

Lemma 2. If $\left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{FAM}} \leq \left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{NO FAM NO R/R}}$

then the firm will use at least as much capital with the FAM.

Proof of Lemma 2. The firm must produce at least Q_0 in the record period in either case. By Lemma 1, with neither FAM nor R/R, the firm will produce exactly Q_0 . Therefore, with the FAM the firm produces at least as much as in the institutionless case. If it used less

capital, it would have to use more fuel, and $\left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{FAM}}$ would be less

than $\left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{NO FAM NO R/R}}$. Employing homotheticity leads to a contradiction

of the original supposition.

Lemma 3. If $\left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{FAM}} \leq \left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{NO FAM NO R/R}}$

then

$$\left(\frac{\bar{K}_2}{\bar{L}_2}\right)_{\text{FAM}} \leq \left(\frac{\bar{K}_2}{\bar{L}_2}\right)_{\text{NO FAM NO R/R}} \quad \forall w_2$$

Proof of Lemma 3. Since the firm gets a review in neither case, it must produce at least $Q(\bar{P}_2)$ in both cases. Since resources are costly, it will produce exactly $Q(\bar{P}_2)$ and not "goldplate" fuel.

By Lemma 2, $\bar{K}_{\text{FAM}} \geq \bar{K}_{\text{NO FAM NO R/R}}$. Therefore, $L_2 \text{ FAM} \leq L_2 \text{ NO FAM NO R/R}$

and $\left(\frac{\bar{K}}{\bar{L}_2}\right)_{\text{FAM}} \geq \left(\frac{\bar{K}}{\bar{L}_2}\right)_{\text{NO FAM NO R/R}}$. The result follows from

homotheticity.

Proof of the Proposition. From the main text, we know that at least one of the following is true:

$$1) \left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{FAM}} > \left(\frac{\bar{K}}{\bar{L}_0}\right)_{\text{NO FAM NO R/R}}$$

$$\begin{aligned}
& \left[\lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{\substack{\text{No FAM} \\ \text{No R/R}}} \\
& \leq \left[\lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right) + \lambda_2 E_2 \left(w_2 \frac{F_{\bar{K}}}{F_{L_2}} - r \right) \right]_{\text{FAM}}
\end{aligned} \quad (4.11)$$

If i) holds, then $\frac{\bar{K}}{L_0} \text{ FAM} < \frac{\bar{K}}{L_0} \text{ NO FAM}$
NO R/R

by homotheticity. Using this and Lemma 1 gives us that $L_0 \text{ FAM} > L_0 \text{ NO FAM}$
NO R/R

This is the second part of (1). If (ii) is true, since w_2 and r are unaffected, Lemma 3 says that

$$\lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right) > \lambda_1 E_1 \left(w_1 \frac{F_{\bar{K}}}{F_{L_1}} - r \right)$$

which reduces to (2) of the proposition.

FOOTNOTES

1. While working on this paper, I became aware of similar research being conducted by Stewart [1977], Cowing and Stevenson [1978], and Baron and De Bondt [1978]. The work presented here differs from all three primarily with regards to the models of the regulatory process which are incorporated.
2. These two formulas are different ways of allowing for an increase in "average fuel costs". Both use the output of period 0 as a base. However, FAM 1 adjusts price to reflect the change in expenditures necessary to purchase the current amount of fuel. FAM 2 reflects, instead, the change in total fuel expenditures from period 0 to period 1.
3. In an A-J rate of return model, the first and second order conditions for the profit maximizing firm are inconsistent with the firm operating in the inelastic part of the demand curve. No such inconsistency arises in the "rate review" of model B. The price formula

$$P_2 = \frac{w_2 L_1 + s\bar{K}}{Q_1}$$

is not that of an A-J instantaneous rate review, which would be

$$P_2 = \frac{w_2 L_2 + s\bar{K}}{Q_2}$$

In fact once period 2 has arrived, the model B firm can do nothing more to alter price, and fuel must be purchased to satisfy

$$F(\bar{K}, L_2) = Q(P_2).$$

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