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A Model of Regulation Under Uncertainty and a Test of Regulatory Bias

by

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I. Introduction

The Averch-Johnson[1] (AJ) model of rate of return regulation implies that when a utility's allowed rate of return is greater than the cost of capital, it will have an incentive to exceed the cost-minimizing capital-labor ratio for the level of output it selects. Since its original presentation, this model has exerted a dominant influence on the theory of public utility regulation, and recently it has received some empirical support.[2] Nevertheless, the model's specification has not gone without criticism. While rate of return testimony is a part of every formal regulatory proceeding, commissions also set the price of the utility's output. Utilities are not free to choose any price consistent with an allowed rate of return constraint, as is assumed in the AJ model. Instead, a price is set, and this price prevails until a proposal for a rate change is made. In the interim, the utility's actual rate of return may fluctuate above or below the allowed rate because of uncertainty, for example, about the demand that will prevail at the prescribed price. Uncertainty makes the regulators' task more difficult in that _ex post_ results cannot be used to assess whether _ex ante_ allowed rates of return and prices have been appropriate. Uncertainty also compounds the utility's problem, since the utility is obligated to satisfy _ex post_ demand, yet it may have relatively fixed factors in the short-run. The utility's available stocks of capital and labor are relatively fixed, for example, while fuel and the factor services generated by the stocks of capital and labor are used as ex post variable factors to satisfy fluctuations in demand. An improved model of regulation, then, should account for price-setting by commissions, the demand uncertainty faced by utilities, and a utility's ability to respond to that uncertainty.

In the model presented in this paper the regulatory commission sets price so as to eliminate monopoly rents for a projected level of demand.[3] Although it will not be possible to eliminate excess or insufficient returns after the fact, a commission can make use of a utility's stock market value to determine if future monopoly rents are anticipated by investors. If the market value of a utility's assets exceeds their reproduction cost, the difference can be attributed to the capitalized value of monopoly rents. The commission will try to eliminate any such rents by lowering the price of the utility's output below the monopoly price until the market value of its assets is equal to their reproduction cost.

When regulatory behavior is viewed in this way, there are three possible outcomes, depending on how the owners of the utility perceive that their investment decisions influence the regulated price of output. If stockholders perceive no connection between their input choices and the allowed price of output, Leland[24] has shown that stockholders will unanimously prefer that the utility produce efficiently. If, however, stockholders anticipate that the regulated price is related to the utility's capital stock, the utility may have an incentive to produce inefficiently, resulting in regulatory bias. If shareholders believe that the regulated price of output will be higher the larger is its capital stock, then as will be shown in the development of the model, the stockholders benefit from overcapitalization. The AJ model, in fact, might be thought of as similar to this case. The third possibility is that stockholders perceive that a larger capital stock is associated with a lower allowed price of output. In this case, stockholders unanimously prefer undercapitalization. If stockholders perceive that their willingness to invest additional capital in the firm will result in the regulator reducing the output price, they may restrict their capital investment in order to obtain a higher allowed output price. The utility would then be acting like a monopolist in the sense that it would be restricting demand.

The model developed in this paper does not predict which of these cases will obtain, so this issue will be left as a matter for empirical testing using data for the electrical utility industry. The model focuses on the preferences of investors for the factor input levels of the firm and uses a stockholders' equilibrium in an incomplete securities market to establish the market value of the firm and to evaluate investor preferences. The model is structured to lead to estimates of the parameters of a Cobb-Douglas production function, the elasticity of demand, and the price anticipation effect. From these estimates the regulatory bias may be evaluated.

In a descriptive sense, the model represents fair-rate-of-return regulation and is designed to reflect price-setting by the regulator, to incorporate demand uncertainty, and to distinguish between *ex ante* fixed factors and *ex post* variable factors. It is not intended to explain the dynamic behavior of a regulatory commission or of the utilities it regulates, but instead the model characterizes an equilibrium at a point in time. Since fair-rate-of-return regulation is applied at the firm level, the model represents the regulated utility as a whole rather than a component of the utility. According to Nerlove[5] "...if we are concerned primarily with the general question of public regulation and with investment decisions and the like, it would seem that the economically relevant entity is the firm. Firms, not plants, are regulated, and it is at the level of the firm that investment decisions are made."

The results of the empirical test indicate that an increase in the capital stock is anticipated to lead to a price reduction and tend to support the hypothesis that there is undercapitalization. The results further suggest that the regulated price is substantially below the price that would result if the utility were an unregulated monopolist. The estimated elasticity of demand agrees with the estimates obtained in other studies,[6] and the estimated factor shares have plausible magnitudes.

The model is presented in Section II, and investor preferences are analyzed in Section III. The empirical test is presented in Section IV, and conclusions are offered in the final section.

II. A Model of an Investor-Owned Regulated Firm

A. Operational Model of an Electrical Utility

The electrical utility industry is composed of both publicly-owned firms and investor-owned firms most of which are regulated on a rate-of-return basis. Since a securities market will be used to determine the regulated price and the optimal levels of factor inputs, only the investor-owned utilities will be considered. While investor-owned utilities represent only about 10% of the electrical utilities, they produce nearly three-quarters of the electricity. These electrical utilities are less homogeneous than might be expected, however, since they engage to different extents in the generation, transmission, and distribution of electricity. They also differ in terms of the technology used to generate electricity, with the principal means being steam, nuclear and hydraulic. The empirical analysis has been restricted to those investor-owned utilities that have a relatively common technology and engage to a comparable extent in the generation, transmission, and distribution of electricity.

Since regulation is applied to an electric utility as a whole and not to individual stages of electricity generation and delivery, the model of the utility's production process will represent the firm as a whole. The production function thus represents the aggregate of the production possiblities of the generation, transmission, and distribution stages. Regulated utilities are obligated to satisfy the demand that occurs at the regulated price, but once the plant and technology of an electric utility are established, there is little possibility for *ex post* substitution among factor inputs. The utility, however, at the planning or *ex ante* stage does have substitution opportunities and must determine the amount of capital to employ and the amount of labor to hire and train. Electric utilities tend not to adjust their stock of labor inputs in response to demand fluctuations and thus treat the labor input as an *ex ante* factor input. Fuel and the services of capital and labor are, however, used *ex post* depending on the level of demand. That is, demand is satisfied, for example, by bringing generators on stream, and the fuel input is thus used in proportion to the demand and the number of generators in service. To model the production process of the utility, it is thus necessary to distinguish between the *ex ante* and the *ex post* production function. The *ex post* production function will be represented by a Leontief function, while a Cobb-Douglas function will be used for the *ex ante* production function.

The *ex ante* function determines the capacity, x, that is available for use to meet the *ex post* demand, and that function will be denoted by

$$x = x(K,L,\overline{f}) = AK^{\alpha}L^{\beta}\overline{f}^{\gamma}, \ \alpha > 0, \ \beta > 0, \ \gamma > 0,$$

where K and L are the stocks of capital and labor, respectively, and $\overline{f}$ is the fuel required to operate at capacity. Once the capacity has been determined, the technology of the firm is assumed to be such that fuel and the factor services of capital and labor are used in fixed proportions to demand.[8] The demand at a regulated price p is assumed to be a multiplicative factor $\tilde{v}$ of a deterministic demand function q(p), so demand is $q(p)\tilde{v}$ where $\tilde{v} \in (0,\infty)$ is a random variable. The *ex post* production function is thus

$$
\begin{aligned}
q(p)\tilde{v} &= a_f\tilde{f} \\
q(p)\tilde{v} &= a_K\tilde{K}_S \qquad \text{where } \tilde{K}_S \le K = x/\xi_K \qquad (1)\\
q(p)\tilde{v} &= a_L\tilde{L}_S \qquad \text{where } \tilde{L}_S \le L = x/\xi_L
\end{aligned}
$$

and $\tilde{K}_S$ and $\tilde{L}_S$ are the services of capital and labor while ξ_K and ξ_L relate capacity and the *ex ante* stocks. The coefficient a_f is the inverse of the heat rate for the utility.[9] Most utilities participate in power pools, so that if demand exceeds capacity, a utiltiy may purchase power to satisfy demand. To simplify the model, purchased power and fuel will be combined into a single factor input,[10] and capacity will thus be assumed sufficient to satisfy demand.

The *ex ante* production function essentially determines the parameters a_f, a_K, and a_L of the *ex post* production function. The emphasis here will be on the *ex ante* production function, but the fuel input $\bar{f}$ at capacity is not observable because most utilities operate at only 50 or 60% of capacity on average. The coefficient a_f of the *ex post* production function can be determined from the *ex ante* production function, since when demand equals capacity, $x = a_f\bar{f}$ and

$$x = x(K,L,\bar{f}) = x(K,L,x/a_f) = AK^{\alpha}L^{\beta}(x/a_f)^{\gamma}.$$

Solving for a_f yields

$$a_f = A^{1/\gamma} K^{\alpha/\gamma} L^{\beta/\gamma} x^{1-1/\gamma}.$$

If the utility has constant returns to scale, $\alpha + \beta + \gamma = 1$, the coefficient a_f is independent of the scale of the inputs. With increasing (decreasing) returns to scale, a_f is increasing (decreasing) with the scale of inputs.[11] The ex ante production choices thus determine the heat rate for the utility.

The Cobb-Douglas specification for the ex ante production function implies that capital and labor are complements and that the elasticity of substitution among factor inputs equals one. Empirical studies of electricity generation at the plant level, such as that of Dhyrmes and Kurz,[12] have found little substitution between capital and labor. Courville[13], using a Cobb-Douglas specification and plant data, found that the output elasticity of labor was negative for one vintage group and not significantly different from zero for two other groups. The ex ante production function used here, however, represents the generation, transmission, and distribution of electricity, and while the labor input is relatively minor at the plant level, it is more important in the transmission and generation stages. Furthermore, capital and labor are likely to be complements in the sense that additional capacity requires additional maintenance, connections, control, and supervision.

The before-tax operating profit $\tilde{\Pi}$ of the regulated firm in a period is

$$\tilde{\Pi} = (1-t)\ pq(p)\tilde{v} - wL - c\tilde{f},$$

where w is the wage rate, c is the factor price of fuel, and t is the sales tax rate applied to the revenue of the firm.[14] Using (1), the before-tax operating profit is

$$\tilde{\Pi} = ((1-t)p-c/a_f)q(p)\tilde{v} -wL. \qquad (2)$$

The term $((1-t)p-c/a_f)$ is the net price minus the fuel cost per unit of demand and constitutes the contribution per unit of demand to the fixed factor inputs, capital and labor. The before-tax operating profit accrues to the investors who provide capital to the firm, and the behavior of those investors is considered in the following section.

B. Securities Market Equilibrium

The investor-owned utilities to be considered here are those whose shares are traded in a securities market, and in a private-ownership economy these firms are presumed to act in the best interests of their shareholders. To determine which actions of the firm are in the best interests of shareholders, a securities market equilibrium will first be characterized, and then the actions preferred by shareholders will be determined in the following section. The role of the securities market is to impute an ex ante value to the uncertain return on the securities of the firm. To simplify the discussion, the model will be presented as a one-period model in which investors make portfolio decisions and firms make capital and labor decisions at the beginning of the period, demand occurs, the firm satisfies that demand, and the firm ceases to exist at the end of the period, distributing its profits to investors. In Section III, where the empirical tests are presented, the model will be extended to a multiperiod horizon.

The return to shareholders is the after-tax profit of the firm less the repayment of any borrowing by the firm. The firm is assumed to borrow an amount D, and the debt carries a gross interest rate r that is determined endogenously in the securities market. The interest $(r-1)D$ on the debt is tax-deductible,[15] so the after-tax profit of the firm is $(\tilde{\Pi}-(r-1)D)(1-T)$, where T is the corporate profits tax rate. All investors will be assumed to believe that there is no risk of default on the interest payments but that there may be default on debt principal, in which case the after-tax profit $(\tilde{\Pi}-(r-1)D)(1-T)$ accrues to bondholders. If the firm does not default on the repayment of debt principal, the return to shareholders is $[(\tilde{\Pi}-(r-1)D)(1-T)-D]$. The firm will default on the debt principal if $\tilde{\Pi} < D/(1-T) + (r-1)D$, so the total return $\tilde{R}_E$ to equity holders is given by

$$\tilde{R}_E = \begin{cases} 0 & \text{if } \tilde{\Pi} < D/(1-T) + (r-1)D \\ (\tilde{\Pi}-(r-1)D)(1-T)-D & \text{if } \tilde{\Pi} \geq D/(1-T) + (r-1)D. \end{cases} \tag{3a}$$

The return $\tilde{R}_D$ to bondholders is given by

$$\tilde{R}_D = \begin{cases} (\tilde{\Pi}-(r-1)D)(1-T) + (r-1)D & \text{if } \Pi < D/(1-T) + (r-1)D \\ rD & \text{if } \Pi \geq D/(1-T) + (r-1)D \end{cases} \tag{3b}$$

At the beginning of the period an investor is assumed to be endowed with an initial ownership proportion $\bar{\gamma}$ of the equity of the firm and an investment $\bar{z}$ in a risk-free asset. The investor may revise his portfolio by purchasing a proportion γ of the equity and by purchasing a proportion δ of the debt D issued by the firm. These investments are restricted by the budget constraint

$$\bar{\gamma}V + \bar{x} = \gamma V + \delta D + z. \tag{4}$$

In general, the investor will have other securities in which he may invest but those opportunities will not be separately denoted. The return $\tilde{R}$ on the investor's portfolio is

$$\tilde{R} = \gamma\tilde{R}_E + \delta\tilde{R}_D + r_o z, \tag{5}$$

where r_o is the gross return on the risk-free asset. Solving (4) for z and substituting into (5) yields

$$\tilde{R} = \gamma(\tilde{R}_E - r_o V) + \delta(\tilde{R}_D - r_o D) + r_o W_o. \tag{6}$$

The terms in parentheses are the net returns on equity and debt, respectively. For example, $\tilde{R}_E$ is the return to equityholders and $r_o V$ is the opportunity cost of foregoing an investment of V in the risk-free asset in order to purchase the equity.

Letting the investor have a strictly concave utility function U the necessary optimality condition for γ and δ are, respectively,

$$\int \rho(\tilde{v}) \cdot (\tilde{R}_E - r_o V) d\tilde{v} = 0 \tag{7}$$

$$\int \rho(\tilde{v}) \cdot (\tilde{R}_D - r_o D) d\tilde{v} = 0 , \tag{8}$$

where $\rho(\tilde{v}) = U'(\tilde{R})\ell(\tilde{v})/E\{U'(\tilde{R})\}$ is the "implicit price" of a unit of return obtained if v occurs and $\ell(\tilde{v})$ is a density function.[17] Since $\int_0^\infty \rho(\tilde{v})d\tilde{v} = 1$, $\rho(v^*)$ may be interpreted as the price the investor is willing to pay for a dollar of return obtained if and only if v* obtains. A dollar to be received if any value of $\tilde{v}$ occurs has a value equal to the sum of the implicit prices, which is normalized to equal one.

An equilibrium in this model will be referred to as a stockholders' equilibrium and involves both an equilibrium in the stock market and an equilibrium for firms in the choice of production plans. A stock market equilibrium is a market value pair (V,r) and portfolio holdings $[(\hat{\gamma}),(\hat{\delta})]$ for each investor such that $(\hat{\gamma},\hat{\delta})$ satisfies (7) and (8) for every investor and the markets clear, which is equivalent to the ownership proportions for debt and equity each summing to one.[18] The appropriate equilibrium concept for firms is a Lindahl equilibrium in which firms may be thought of as maximizing their values using a weighted sum of the implicit prices of investors to develop a "market certainty equivalent" for the uncertainty they face. Conditions under which an equilibrium exists are given by Drèze[19] and will not be presented here. An equilibrium will be assumed to exist for every regulatory price the regulator may set for which the equilibrium market value V is positive. In addition, a regulated price is assumed to exist such that the market value of the firm equals the capital stock at a stockholders' equilibrium.

C. Shareholder Preferred Inputs

To determine the levels of K and L that are in the interests of shareholders, the recent work on shareholder unanimity will be used.[20] The forms of the return functions in (3a) and (3b) are such that the spanning property[21] is satisfied and coupled with the assumption that investors act as price takers with respect to their implicit prices, all initial shareholders ($\bar{Y} > 0$) may be shown to prefer that the firm act to maximize its market value as perceived by shareholders. The price-taking assumption implies that the investors use their implicit prices to predict the change in the value of the firm that will result from a change in the labor input and the capital investment. Although different investors will have different implicit prices,[22] with the spanning condition and the price-taking assumption all investors will perceive or forecast the same change in the value of the firm. Shareholders will then be unanimous in their preferences for changes in the decisions of the firm, and all shareholders will prefer the decisions that maximize the perceived value of the firm.

Investor preferences are indicated by the partial derivatives of expected utility evaluated at a stockholders' equilibrium for a given regulated price. To determine the investor's preference for levels of the capital stock, the incremental unit of capital will be taken to be financed with a proportion θ of debt. The marginal cost of capital is r_o, the opportunity cost of a dollar invested in the firm less the marginal tax saving on new debt, $\theta T(r-1+\frac{\partial r}{\partial D} D)$.

The (normalized) investor's preferences thus may be shown to be (see Appendix A)[23,24]

$$\frac{\partial EU(\tilde{R})}{\partial K} = \int_0^\infty \rho(\tilde{v})\bar{\gamma}\ [\ \frac{\partial \tilde{\Pi}}{\partial K}\ (1-T) + \theta T(r-1 + \frac{\partial r}{\partial D}D) - r_o]d\tilde{v} \qquad (9)$$

$$\frac{\partial EU(\tilde{R})}{\partial L} = \int_0^\infty \rho(\tilde{v})\bar{\gamma}\ \frac{\partial \tilde{\Pi}}{\partial L}\ (1-T)d\tilde{v}, \qquad (10)$$

where the marginal profits are

$$\frac{\partial \tilde{\Pi}}{\partial K} = ((c/a_f^2)\frac{\partial a_f}{\partial K}\ q(p) + (MR-q'(p)c/a_f)\frac{\partial p}{\partial K}\ )\tilde{v} \qquad (11)$$

$$\frac{\partial \tilde{\Pi}}{\partial L} = (c/a_f^2)\frac{\partial a_f}{\partial L}\ q(p)\tilde{v} - w\ , \qquad (12)$$

and $MR = (q(p) + pq'(p))(1-t)$ is marginal revenue with respect to price. For labor, shareholder preferences depend on the difference between marginal fuel savings $(c/a_f^2)\partial a_f/\partial L\ q(p)\tilde{v}$ and the marginal cost, w, of labor. The investor's preferences for the capital investment depend on the difference between the marginal fuel savings $(c/a_f^2)\partial a_f/\partial K q(p)\tilde{v}$ and the marginal cost $(r_o - \theta T(\frac{\partial r}{\partial D}D + r-1))$ of capital plus a regulatory bias term $(MR-q'(p)c/a_f)\frac{\partial p}{\partial K}\ \tilde{v}$. The interpretation of the regulatory bias term will be given in the next section, and the evaluation of that effect will be presented here.

The marginal profits in (11) and (12) depend on how the investor evaluates the effect of uncertainty, and the securities market equilibrium conditions may be used to show that all investors use the same "certainty equivalent" v* to evaluate the demand uncertainty. The certainty equivalent may be determined by adding (7) and (8) and solving for $\int_0^\infty \rho(\tilde{v})\tilde{v}d\tilde{v}$ as

$$\int_0^\infty \rho(\tilde{v})\tilde{v}d\tilde{v} = [r_o(V+D)-T(r-1)D+wL(1-T)]/$$

$$[((1-t)p-c/a_f)q(p)(1-T)] \equiv v^* \qquad (13)$$

The numerator of v^* represents the payments to the ex ante factors less the tax deduction from the interest payments, and the denominator is the after-tax contribution of the ex post activity of the firm. The right side is independent of any investor characteristics so all investors use the same certainty equivalent.[25] The certainty equivalent v^* may also be interpreted as a market expectation of v^*, since the implicit prices may be viewed as market probabilities.[26] Furthermore, since $\rho(\tilde{v}) > 0$ for $g(\tilde{v}) > 0$ and $\tilde{v} > 0$, $((1-t)p-c/h) \geq 0$, so the firm operates such that the net price $(1-t)p$ exceeds the marginal fuel cost.

Substituting v^* into (9) and (10) indicates that the signs of the expected marginal utilities are the same for all initial shareholders ($\overline{Y} > 0$), so all initial shareholders have unaminous preferences for the levels of K and L. The preferred levels of labor L^* and capital K^* are those that equate the marginal expected utilities in (9) and (10) to zero and thus maximize the expected utility of the initial shareholders. The preferred levels K^* and L^* thus satisfy the following optimality conditions

$$[(c/a_f^2)\,\frac{\partial a_f}{\partial K}q(p) + (MR-q'(p)c/a_f)\partial p/\partial K]v^*(1-T)$$

$$-(r_o-\theta T(\frac{\partial r}{\partial D}D+r-1)) = 0 \qquad (14)$$

$$(c/a_f)\frac{\partial a_f}{\partial L}\,q(p)v^*(1-T) - w(1-T) = 0, \qquad (15)$$

where v^* is evaluated at K^* and L^*.

The first terms in (14) and (15) are the certainty equivalent marginal contributions to profit while the second terms are the after-tax marginal costs of capital and labor. The levels of capital and labor satisfying (14) and (15) maximize the expected utility for all initial shareholders,[27] and those levels are _ex ante_ (constrained) Pareto optimal.[28]

D. Regulatory Policy

In this model regulators are viewed as attempting to eliminate monopoly rents by setting a price below that which a monopolist would set.[29] The monopoly rents in this case are the difference between the market value of the firm and the capital supplied by investors, and the regulator would seek to set a price so that difference is zero. This regulatory principle is much the same as the usual concept of rate-of-return regulation. The capital stock may be thought of as the rate base, and the fair rate of return is that needed to generate a market value equal to that rate base. Because profit is uncertain, one is not able to speak of the <u>ex post</u> rate of return, but the <u>ex ante</u> or certainty equivalent fair rate of return may be defined as the certainty equivalent profit divided by the market value V + D of the firm. That market value may be derived from (14) as

$$V+D = \frac{1}{r_o}\left[(r_o - \theta T(\tfrac{\partial r}{\partial D}D+r-1))\frac{(p(1-t)-(c/a_f))q(p)}{(c/a_f^2)\frac{\partial a_f}{\partial K}q(p)+(MR-q'(p)c/a_f)\frac{\partial p}{\partial K}}\right.$$

$$\left. - wL(1-T) + T(r-1)D\right]. \qquad (16)$$

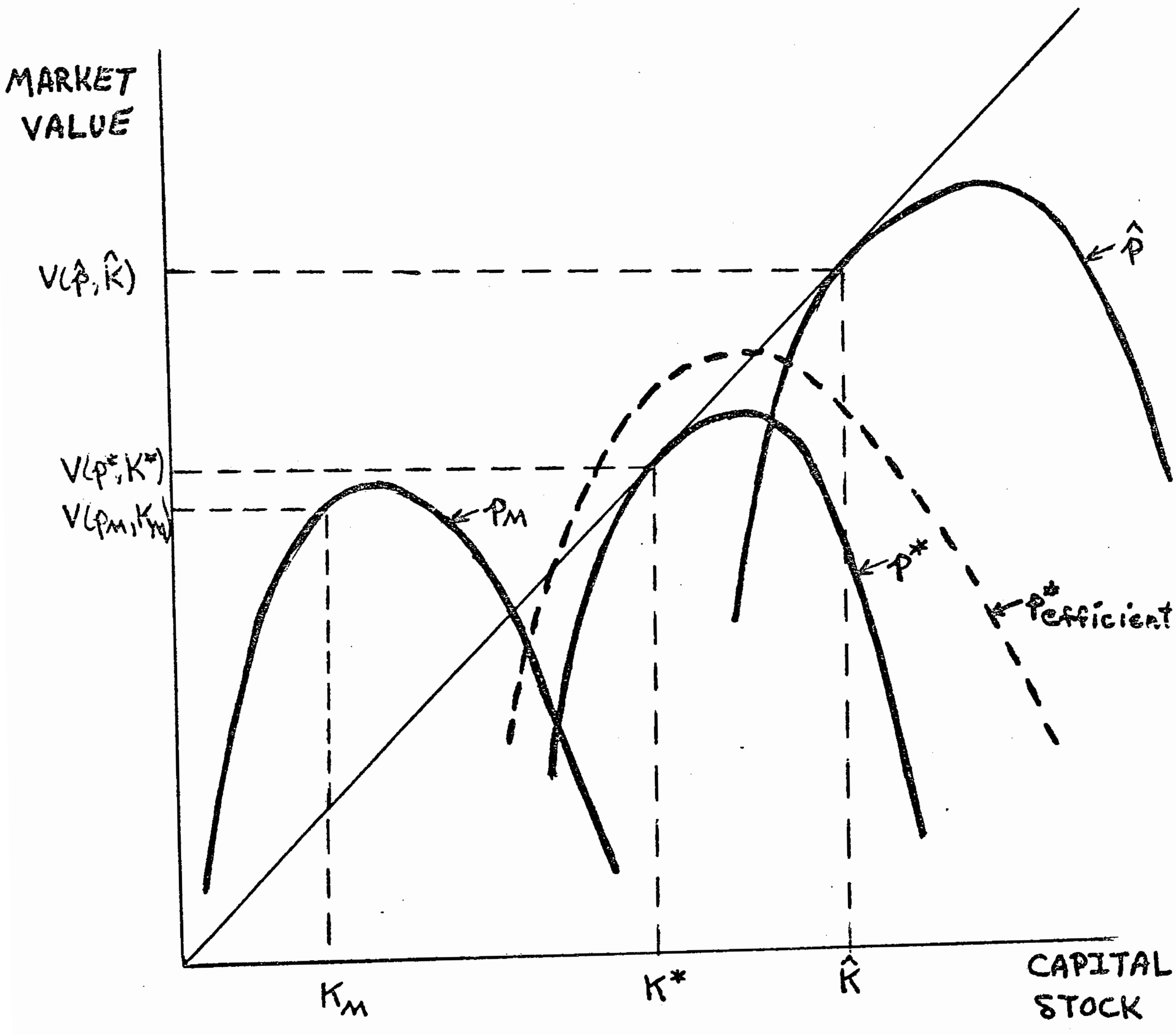
The term in brackets is the certainty-equivalent (after-tax) profit, which equals the marginal revenue product of capital less the wage payments plus the tax-savings from the interest payments. Dividing the certainty-equivalent profit by the market value indicates that the fair rate of return is equal to the risk-free rate of interest. This is as would be expected, since at a stockholders' equilibrium the value imputed by each investor to the rate of return on every security equals the risk-free rate as can be seen from (7) and (8).

This regulatory principle is illustrated in Figure 1 in which the value of the firm is graphed against the capital stock for various output prices. In order to avoid consideration of the financing problem, it is assumed in the diagram that all capital is rented. If the regulator set the monopoly price p_M, the shareholders would prefer a capital stock K_M that maximizes the rents from the firm.[30] The shareholders would then receive the rents that are given by the difference between the value of the firm and the capital stock (the distance between $V(p_M,K_M)$ and the diagonal). To reduce these rents, the regulator may lower the price to $\bar{p}$, and shareholders will increase their investment even though the rents are reduced. To see that a price decrease would likely increase the preferred capital level, consider the case in which there is no price anticipation. If $\bar{p} < p_M$, then evaluating at (K_M,L_M) yields

$$(c/a_f^2)\frac{\partial a_f}{\partial K}\, q(\bar{p}) > (c/a_f^2)\frac{\partial a_f}{\partial K}\, q(p_M),$$

so the expression in (14) is positive at $\bar{p}$. The shareholders thus prefer to increase the capital stock. If the firm continued to produce efficiently, the regulator would then lower the price to $\hat{p}$ at which the market value function is tangent to the diagonal. At that price investors would prefer to invest $\hat{K}$ and the market value of the firm would equal the capital stock, so all monopoly rents would be eliminated. The regulator would not wish to reduce the price below $\hat{p}$ because the market value would fall below the value of the capital stock and the shareholders would not receive a fair return.[31]

Figure 1


MARKET
VALUE
$V(\hat{p},\hat{K})$
$V(p^*,K^*)$
$V(p_M,K_M)$
p_M
p^*
$\hat{p}$
$p^*_{efficient}$
K_M
K^*
$\hat{K}$
CAPITAL
STOCK

E. Regulatory Bias

The price $\hat{p}$ in Figure 1 is the lowest price that the regulator may choose, but if shareholders anticipate a relationship between the capital they provide and the price set by the regulator, monopoly rents may be eliminated at a price p* higher than $\hat{p}$. In this case, the monopoly rents would be eliminated by inefficient production even though the price is higher than $\hat{p}$. If the price p* is set by the regulator, the firm could earn monopoly rents if it produced efficiently as indicated by the dotted curve labelled $p^*_{efficient}$, but if the firm did produce efficiently, the regulator would reduce the price further. To prevent further price reductions, the firm may produce inefficiently. Anticipation of a regulatory price response might be expected because the test that the regulator would use to determine if the price should be lowered further is the willingness of shareholders to invest more capital in the firm. If shareholders respond to a price decrease by increasing their investment, a further price decrease would be enacted by the regulator. Shareholders might thus be expected to anticipate that an increase in the capital stock would lead to a further price reduction or that $\frac{\partial p}{\partial K} < 0$. At prices below the monopoly price the marginal profit with respect to price would be expected to be positive, so that the term $(MR-q'(p)c/a_f)\frac{\partial p}{\partial K}$ would be negative.[32]

To determine the effect of this price anticipation, the conditions in (14) and (15) may be used to obtain

$$\frac{\partial a_f/\partial K}{\partial a_f/\partial L} + \frac{(MR-cq'(p^*)/a_f)\frac{\partial p}{\partial K}}{(c/a_f^2)\frac{\partial a_f}{\partial L}\,q(p^*)} = \frac{(r_o - \theta T(\frac{\partial r}{\partial D}D+r-1))}{w(1-T)}. \tag{17}$$

The right-side is the ratio of the after-tax marginal costs of capital and labor. The first term on the left-side is the ratio of the marginal products, as indicated in Appendix A, and the second term is the regulatory bias resulting from anticipation of a regulatory price response to an increase in the capital stock.[33] If the numerator of the second term is negative (positive), undercapitalization (overcapitalization) would result. As argued above, the term $(MR-q'(p^*)c/a_f)$ is likely to be positive for $p^* < p_M$, so the direction of the bias would be indicated by the price anticipation term $\frac{\partial p}{\partial K}$. If this term is negative, undercapitalization would result. Regardless of the sign of the regulatory bias, that bias is unanimously preferred by all initial shareholders and results in an <u>ex ante</u> constrained Pareto optimal resource allocation.

The model presented here does not predict that inefficiencies will result, since no <u>a priori</u> assumption is made about the presence of price anticipation. Instead, the model indicates the possibility of regulatory bias resulting from price anticipation and treats its presence or absence as an empirical question to be investigated in Section IV.

The above discussion has indicated that if there is price anticipation and marginal profit with respect to price is nonzero, regulatory bias will result. If it does result, a natural question that arises is why the regulator does not set the price $\hat{p}$ and force the firm to produce efficiently. Shareholders would be as well off at $\hat{p}$ with efficient production as they would be at p^*

with inefficient production, since monopoly rents would be eliminated in either case. One response to this question is that the regulator would have no idea if the firm were producing efficiently or inefficiently, since it can only observe the relationship between the market value of the firm and the capital stock and cannot check the condition in (17). Leland makes the strong implicit assumption that the regulator can actually determine that $\hat{p}$ is the lowest price that may be set, but such an assumption does not seem to be realistic.

An analogous question is what incentive does a firm have to operate inefficiently if shareholders will be as well off at $\hat{p}$ as at p^*. That is, if shareholders know that all monopoly rents will be eliminated, they do not have an incentive to either operate the firm efficiently or inefficiently. This is the same result that obtains in an AJ model when the allowed rate of return equals the cost of capital (i.e. monopoly rents are eliminated) as pointed out by Baumol and Klevorick.[34] In the AJ model, if the firm then has a goal of maximizing output, efficient production will result. In the context of the model presented here the regulator choosing the lowest price $\hat{p}$ which eliminates monopoly rents is equivalent to maximizing output. The process of lowering the regulated price from the monopoly price p_M in order to eliminate the monopoly rents also corresponds to the lowering of the allowed rate of return towards the cost of capital in an AJ model. In the two models the firm responds by increasing output and the capital input, respectively.

To answer the question of a possible motive to produce inefficiently, it is necessary to step outside the scope of the simple model presented here. One possibility is that shareholders believe that the regulator may make a mistake and set a price so low that the value of the firm would be less than the capital stock. Since regulators are much less likely to approve requests by firms for price increases than they are to lower prices, as Joskow[35] has indicated, shareholders might fear that such a mistake would not be rectified if it were made. They would then prefer to settle at a price p^* greater than $\hat{p}$ so that there is a cushion in case a price decrease were imposed in the future.

Another possible explanation of price anticipation involves regulatory lag. If an equilibrium is achieved at (p^*, K^*, L^*), and that price will be in effect over a period of time, the firm may be able to alter its capital and labor inputs somewhat to produce more efficiently. The initial shareholders would then capture some rents during the period between reviews.[36] Joskow[37] states that regulators are interested in preventing prices from rising, and if this view is correct, there may be relatively little initiative for future price reductions on the part of regulators. Predicting the magnitude of this effect would require a model with a broader scope than the one presented here. If this explanation is correct, less inefficient production would be expected to occur between reviews. Regulatory bias should show up most strongly for utilities in the midst of a rate hearing or about to file for a rate increase.

III. The Empirical Test

A. The Estimated Equations

To test if there is price anticipation and regulatory bias, the equilibrium condition in (14) may be rewritten as

$$\frac{((1-t)p^*-c/a_f)q(p^*)(r_o-\theta T(\frac{\partial r}{\partial D}D^*+r-1))}{(r_o(V+D^*)-T(r-1)D^*+wL^*(1-T))} = \frac{c}{a_f^2}\frac{\partial a_f}{\partial K}q(p^*)$$

$$+ \quad (MR - (c/a_f)q'(p^*))\frac{\partial p^*}{\partial K}. \qquad (18)$$

As indicated in Appendix A, for a Cobb-Douglas production function, the right side may be rewritten, after dividing by $(c/a_f)q(p^*)$, as

$$\frac{((1-t)p^*/(c/a_f)-1)(r_o-\theta T(\frac{\partial r}{\partial D}D^*+r-1))}{[\, r_o(V+D^*)-T(r-1)D^*+wL^*(1-T)\,]} = \frac{\alpha}{K^*}$$

$$+ \quad (MR/(c/a_f) - q'(p^*))\frac{\partial p^*}{\partial K}/q(p^*). \quad (19)$$

where a_f is the inverse of the heat rate at peak operation. If the left side of (19) is regressed on $1/K^*$, the estimated constant in the regression will be an estimate of the second term on the right-side and the slope will be an estimate $\hat{\alpha}$ of α. The hypothesis that there is no anticipation of regulatory price setting is equivalent to the constant being equal to zero. If there is anticipation, the constant should be negative. The error term in the regression may be thought of as a managerial variation reflecting the ability of management to choose the factor input levels optimally. This variation may arise as well from imperfect information about the price anticipation term.

The equilibrium condition in (15) for labor may be rewritten as

$$\frac{((1-t)p^*/(c/a_f)-1)w(1-T)}{[r_o(V+D^*)-T(r-1)D^*+wL^*(1-T)]} = \beta/L^*, \tag{20}$$

to obtain an estimate $\hat{\beta}$ of the output elasticity β of labor. The estimated constant should be zero in this regression.

State regulatory commissions use either an historical cost or a fair-value basis for determining the value of a utility's capital stock. To take into account the difference between these two bases, a 0-1 dummy variable FAIR is added to the right sides of (19) and (20) with 1 indicating a fair value basis. Certain state commissions are considered to be more "progressive" than others, so another 0-1 dummy variable PROG was added to the right sides of (19) and (20) with 1 indicating progressive. The progressive commissions, as identified by Joskow [10], are those in California, New York, and Wisconsin, and all use an historical cost basis.

To further investigate the possible presence of regulatory bias, the last term in (19) may be written as

$$(MR/(c/a_f)-q'(p^*))\,\frac{\partial p^*}{\partial K}\Big/\,q(p^*) = [(1-\eta)(1-t)/(c/a_f)$$

$$- q'(p^*)/q(p^*)]\,\frac{\partial p^*}{\partial K},$$

where η is the elasticity of demand. The term $(-q'(p*)/q(p))$ is positive, while the sign of the term $(1-\eta)(1-t)/(c/a_f)$ depends on the elasticity of long-run demand which has most often been found to be greater than one.[38] In order to estimate the components of the regulatory bias term, a constant elasticity of demand function will be considered. With that assumption the equation in (19) is

$$\frac{((1-t)p^*/(c/a_f)-1)(r_o-\theta T(\frac{\partial r}{\partial D}D^*+r-1))}{[\ r_o(V+D^*)-T(r-1)D^*+wL^*(1-T)\ ]} = \frac{\alpha}{K^*} + b_1\text{FAIR} + b_2\text{PROG}$$

$$+ (1/p-(1-t)/(c/a_f))\eta\frac{\partial p^*}{\partial K} + ((1-t)/(c/a_f))\frac{\partial p^*}{\partial K}\ , \qquad (21)$$

where b_1 and b_2 are the coefficients of the two dummy variables. Using this condition in (19) will yield estimates of the price anticipation effect $\frac{\partial p^*}{\partial K}$ and the product $\eta\ \frac{\partial p^*}{\partial K}$. Letting b_3 and b_4 be the respective estimators, a (biased) estimate of η is b_4/b_3.

B. A Multiperiod Formulation

The model presented above is a one-period (i.e., two points in time) model, but the capital stock K of a firm may be utilized over many periods. If the model is extended so that the firm faces an infinite number of identical periods, the present value of the firm's profit is

$$\tilde{\Pi}y = ((1-t)p^*-c/a_f)q(p^*)\tilde{v}y-wL^*y$$

where y is a present value factor. The present value of the after-tax return to equity holders if the firm doesn't default is

$$\tilde{R}_E y = ((1-t)p^*-c/a_f)q(p^*)\tilde{v}y-wL^*y-(r-1)D^*y)(1-T)$$

With the inclusion of the term y, the expression corresponding to (20) is changed only by multiplying the one-period cash flows $[-T(r-1)D^{*}+wL^{*}(1-T)]$ by y and the marginal tax savings $\theta T(\frac{\partial r}{\partial D} D^{*}+r-1)$ by y. Since these cash flows are certain, the appropriate value for y is the discounted sum of the cash flows over an infinite horizon so that $y = r_o/(r_o-1)$. The model thus represents an infinite horizon with identical periods where all investors follow a buy and hold strategy.

The capital stock itself depreciates over time and the firm must retain earnings to maintain the capital stock at a level K. If (economic and accounting) depreciation occurs on a straight-line basis at a rate of Ψ, the present value of the total reinvestment over an infinite horizon is ΨyK. Since, however, the depreciation is tax deductible, the amount is $\Psi yK(1-T)$. The marginal cost of capital thus includes the term $\Psi y(1-T)$. This formulation assumes that the bonds of the firm are consols that involve no repayment of principal and that all reinvestment necessary to cover economic depreciation is a deduction from returns to shareholders. The left side of (19) is then

$$\frac{((1-t)p^{*}/(c\ /a_f)-1)(r_o-\theta T(\frac{\partial r}{\partial D} D^{*}+r-1)+\Psi y(1-T))}{[r_o(V+D)-T(r-1)D^{*}y+wL^{*}(1-T)y+\Psi y(1-T)K^{*}]}, \qquad (22)$$

and the denominator of the left side of (20) is altered in a similar manner.

C. The Sample and Data Measurement

The operating data for the electrical utilities are taken from FPC reports[39], and the financial data are obtained from the COMPUSTAT files. The data exclude all holding companies, as well as all utilities with at least one-quarter of their output accounted for by hydroelectric generation, since that production technology is quite different from steam generation technologies. In particular, hydroelectric generation does not involve the use of fuel as a variable factor to respond to demand. Because electrical utilities differ in the extent of their partici-pation in the generation, transmission, and distribution of electricity, those utilities were excluded that generated less than 70% of the electricity available for transmission or sold more than 20% for resale by other utilities. Utilities with sales less than two billion KWH were also excluded. Forty-eight utilities satisfied these criteria.[40] A subset of this sample was selected to cprrespond to the sample used by Spann.[41] That subset contains those utilities that generate at least 90% of the electricity they generate and receive and sell no more than 10% for resale and thus is more homogeneous in terms of generation, transmission, and distri-bution than is the larger group.[42]

The definitions of the variables used in the analysis are presented in Appendix B, and only two important measurement problems are discussed here. The first is concerned with the term c/a_f. where a_f is given by $a_f=\bar{f}/x$ and $\bar{f}$ is the fuel consumption at capacity. The term $\bar{f}/x$ is the heat rate at capacity, but data are not available to measure that rate. It is possible to measure the heat rate for a utility at the percent of capacity at which it operates on average, but it is known that the peak heat rate is greater than that at normal operations. One method of estimating the peak heat rate is to assume that it depends on the percent of capacity $(q(p)v/x) \equiv \varphi$ at which the utility operates. The fuel actually burned will be assumed to depend on a function $g(\varphi)$ according to the relationship

$$f = \left(\frac{q(p)v}{a_f}\right)g(\varphi) \tag{22}$$

At capacity, $\varphi=1$, and if $g(\varphi)=1$, $\bar{f} = q(p)\bar{v}/a_f = x/a_f$ as required by (1), where $\bar{v}$ is the value of $\tilde{v}$ at which demand equals capacity. At a lower percentage of capacity the fuel consumed per unit of output would be less. From (22)

$$\frac{\bar{f}}{x} = \frac{1}{a_f} = \frac{f}{q(p)v\ g(\varphi)}$$

The term (cf/x) will thus be measured as the actual fuel expenditure per unit of demand divided by a function of the percent of capacity at which the utility operated. The function $g(\varphi)$ is specified as

$$g(\varphi) = \begin{cases} .6 & \text{if } \varphi \leq .6 \\ .6 + (.4/.16)(.6-\varphi)^2 & \text{if } \varphi > .6. \end{cases}$$

Fuel consumed is thus a convex function of φ. The magnitude of the estimates but not their signs are affected by the specification of g.

The second measurement problem pertains to the "Taxes Other Than Income" that are assessed on utilities. These taxes can amount to more than 20% of revenues and are likely to be assessed on both revenue and the capital stock of the utility. These taxes were regressed on revenue and the capital stock, and the coefficients used to determine the tax rate t on revenue and a tax rate on K. The latter was then added to the marginal cost of capital and to the payments to *ex ante* factors in the denominators of (19),(20), and (21).

IV. Empirical Results

The basic estimates are presented in Tables 1-3. These correspond to equations (19), (20) and (21) except that the multiperiod formulation has been used and the dummy variables PROG and FAIR have been inserted in all three equations.[43] In each table, estimates are presented for four different subsamples: the entire sample of 48 utilities, the 22 utilities with 2-6 billion KWH sales in 1970, the 26 utilities with more than 6 billion KWH sales, and the 26 utilities that satisfy Spann's selection criteria.

The estimates of the optimal capital equation (19) in Table 1 reveal a significantly negative constant term for the ALL sample and the group of large utilities, suggesting that input choices are biased toward undercapitalization. The constant term is not significantly different from zero, however, for either the SPANN group or the sample of small utilities. Estimates of the output elasticity of capital range from .529 to 1.102 and the dummy variables PROG and FAIR display some explanatory power for the ALL and large utility groups. With the exception of the small utility group, the equation fits the data moderately well.

Estimates of the optimal labor equation (20) are presented in Table 2. The fits here are somewhat better than for the previous equation, with the group of small utilities again showing the poorest fit. The constant term is not significantly different from zero in any of the estimates, as the model predicts, while the estimated output elasticities of labor are all highly significant. These range in size from .351 for the SPANN group to .512 for the group of small utilities. Again the progressive dummy variable exerts some influence, although its sign is negative for the small utility group while it is positive for the other three groups.

To investigate the regulatory bias in more detail, the capital equation incorporating the terms in (21) was estimated. As shown in Table 3 the fits for this equation are much better for all four groups and are dramatically better for the group of small utilities. Most of the coefficients are larger relative to their standard errors than are the coefficients in Table 1. This specification should provide more efficient estimates, since it makes use of available information on prices, fuel costs and heat rates, all of which are subsumed in the constant term in equation (19). The results for this equation also tend to support the undercapitalization hypothesis. The price anticipation term is negative and highly significant for all four groups.

Since the coefficient of PROG also has a negative sign, the implication is that the undercapitalization bias is less strong in the progressive states. That is, other things equal, utilities in progressive states will use more capital relative to labor than do other utilities. Since PROG has a positive coefficient in the labor equation, utilities in progressive states may also use more labor, consistent with the notion that labor and capital are complements in the generation, transmission, and distribution of electricity. PROG's coefficient in Table 3 is significantly negative for only the ALL and large utility groups, however, and its sign is the opposite of that reported in Table 1, so the effect should be interpreted with caution.

Contrary to the model's prediction the constant term is significantly different from zero for the ALL sample. It is not significant for the other subgroups, though, so it may represent a nonlinearity in the relationship between small and large utilities.

Finally, the estimated output elasticities of capital are all significantly positive, ranging from .646 to 1.142. As seems reasonable, the group of small utilities has the largest output elasticity of capital.

Further light can be shed on the meaning of these estimates and their consistency with other reported results by investigating the bias term in more detail. The estimate of $\eta \frac{\partial p}{\partial K}$ implies that demand is elastic, and as shown in Table 4, the calculated elasticities vary between 1.45 and 1.50.[44] These results are consistent with those of other studies of the demand for electricity as summarized by Taylor.[45]

The marginal profit per unit of output, $[(1-\eta)(1-t)+\frac{c}{a_f}\frac{\eta}{p}]$, and the bias, the second term in equation (17), have also been computed, and mean values for the various sample groups are reported in Table 5. The calculated marginal profits are positive for all but three utilities in the sample, and the mean values are all in excess of their standard deviations. This suggests that regulatory commissions do indeed constrain the profits of utilities as the model predicts. In addition, most of the utilities with unusually high fuel costs relative to other firms in the sample have high calculated marginal profits.

Since many of these same companies were lining up for rate increases in 1970 on the basis of higher costs, it seems reasonable that they should be most constrained by regulation. A unit increase in price for these companies would yield the greatest additional profit.

The calculated mean input bias terms are also shown in Table 5. These are somewhat smaller relative to their sample standard deviations than are the marginal profits, but the mean values do have a negative sign. This finding is not guaranteed by the regression coefficients and lends further support to the undercapitalization hypothesis. Independent calculations of the mean capital to labor factor price ratios and marginal product ratios are reported for the sake of comparison with the calculated bias. In each case, the marginal product ratio exceeds the factor price ratio indicating undercapitalization, but the bias is larger than the difference between the marginal product and factor price ratios. The bias and the difference, however, are not significantly different relative to the standard deviation of the calculated bias.

In Table 6, the ratio of the estimated output elasticities are presented with the estimated returns to scale and the mean factor share ratio of capital to labor.[46] The estimated factor share ratio is quite close to the mean of the actual ratios for the ALL, large utility, and SPANN groups, but for the small utility group, it overestimates somewhat the mean actual ratio. The estimated returns to scale seem generally plausible in magnitude, and returns to scale appear to be greater for small than for large utilities. This is in agreement with other reported results.[47]

V. Discussion

The regulatory model presented here views the regulator as following the principle of setting a price that yields a fair rate of return to shareholders and allows the firm to raise the capital necessary to satisfy demand. The lowest price that equates the market value of the firm and the value of the firm's capital stock would be optimal from the regulators' standpoint, since efficient production would take place without monopoly rents accruing to investors. But if investors anticipate that the price set by the regulator depends on the amount of capital they decide to invest in the firm, they may prefer that the firm not produce efficiently. The empirical results indicate that this price anticipation term is significantly negative. If the marginal profit is positive as one might expect for a regulatory price less than the monopoly price, the capital bias will be the opposite of that predicted by the Averch-Johnson model. That is, the ratio of the marginal product of capital to labor will exceed the factor price ratio. The empirical results presented here tend to support the existence of this type of bias. The mean marginal profit is positive, and the marginal product ratio is greater than the factor price ratio. These results, however, are only weakly significant. Furhtermore, the difference between marginal product and factor price ratios varies across firms in the sample. Additional testing might be aimed at investigating whether firms engaged in rate hearings are more likely to produce inefficiently.

The regulatory bias indicated by this study is the opposite of that predicted by the AJ model and observed by Courville, Spann, and Petersen. While each of these studies involve substantial measurement problems, as does this study, the basic difference in the results is likely to result from the fundamental differences in the models of regulatory and firm behavior. Spann's observed result that the regulatory constraint in the AJ model is binding is not, in itself, inconsistent with the results presented here, since setting the output price so that the market value equals the value of the capital stock also implies a restriction on achievable profit. When Spann uses the book value to measure the capital stock, his firm data do not support the predictions of the AJ model using his second test of hypotheses. In his first test (that the multiplier λ on the rate of return constraint equals zero) Spann seems to be assuming the alternative hypothesis by assuming that the ex post rate of return equals the allowed rate of return, so his confirmation of the alternative hypothesis is not surprising.

Courville's empirical estimation yields disturbing estimates of the output elasticity of labor and conflicting estimates of the output elasticity of capital. Besides the evident measurement problems, Courville's empirical test is based on the direct estimation of a production function, which does not take into account the optimizing behavior of the firm implied by the AJ model. The observed factor inputs should be constrained by the optimality conditions, but the effect of this restriction is difficult to predict. Furthermore, the regulatory constraint in an AJ model is applied to the entire firm and not to each individual unit within the firm as Courville assumes in his empirical tests.

Petersen estimates a cost function and infers that both total utility costs and the percentage of costs paid to capital increase as the rate of return constraint as tightened. Although Petersen's model is cast in the AJ framework, neither of these results is necessarily inconsistent with the findings in this paper. In the context of the model presented here, a tighter regulatory constraint corresponds to a lower regulated price. The lower price increases demand and hence total cost, but the effect on the factor share of capital is difficult to predict.

The primary weaknesses of the results presented here are the naive assumptions made regarding the dynamics of investor and firm behavior, the aggregation problems involved in firm-level data, and the measurement of some of the variables used in the estimation.[48] The model on which these results are based seems, however, to be a better representation of the actual regulatory process and the nature of electrical utility production than is the AJ model.

Another weakness of this model is the naive behavior ascribed to the regulator who is assumed to have the sole objective of choosing as low a price as possible while leaving the return to investors sufficient to attract the necessary capital to the firm. This regulatory behavior does not guarantee that the firm will produce efficiently, and if it does not, the regulator is not assumed to take any other action. More sophisticated behavior would involve having the regulator choose regulatory instruments or incentives to eliminate any biases created by its price-setting behavior.

The empirical results presented here support the view that investors anticipate that changes in the firm's capital stock will result in a change in the regulated price, and the marginal profit with respect to price is positive for almost all of the utilities. In contrast to the evidence presented by Stigler and Friedland and Moore[49], this suggests that the regulated price is substantially below the price that would be set by an unregulated monopolist.

The empirical evidence presented here is for 1970 which marked a turning point in the cost structure of electricity generation. According to Joskow[50], "Production costs for electric utilities fall rapidly from 1961-1966, are then approximately level from 1966-1969, and begin rising rapidly in 1969." The number of rate reviews by state regulatory agencies correspondingly increased from 5 in 1968 to 31 in 1970 and 53 in 1972.[51] The 1970 data may thus represent a time at which the regulated price for many utilities was not in equilibrium. Empirical studies of the theory presented herein for the 1966-69 period and the post-1970 period may provide further evidence on the regulatory theory proposed by Joskow.

Table I

ESTIMATES OF EQUATION 19

Group	α	PROG*	FAIR**	Constant*	n	R^2
ALL	.919 (10.42)	.102 (2.38)	.254 (1.81)	-.371 (-2.30)	48	.720
2-6	.529 (1.64)	-.653 (-.84)	-2.395 (-.14)	.922 (.33)	22	.244
6+	1.102 (6.95)	.140 (2.57)	.432 (2.17)	-.631 (-2.49)	26	.660
Spann	.810 (5.13)	.207 (1.61)	.093 (.20)	-.277 (-.73)	26	.697

Note = t-statistics are reported below the estimated coefficients.

*The estimated coefficient is the reported coefficient multiplied by 10^{-9}.

**The estimated coefficient is the reported coefficient multiplied by 10^{-13}.

Table 2

ESTIMATES OF EQUATION 20

Group	β	PROG*	FAIR**	Constant*	n	R^2
ALL	.410 (12.13)	.565 (2.11)	-.290 (-.37)	.013 (.02)	48	.832
2-6	.512 (4.16)	-7.827 (-1.80)	164.2 (1.72)	-21.44 (-1.35)	22	.523
6+	.419 (7.70)	.594 (1.80)	-.178 (-.18)	-.155 (-.14)	26	.782
Spann	.351 (4.94)	1.447 (1.43)	-2.318 (-.69)	1.667 (.65)	26	.791

Note = t-statistics are reported below the estimated coefficients.

*The estimated coefficient is the reported coefficient multiplied by 10^{-10}.

**The estimated coefficient is the reported coefficient multiplied by 10^{-14}.

Table 3

ESTIMATES OF EQUATION 21

Group	α	$\frac{\partial p}{\partial K}^*$	$\eta\frac{\partial p}{\partial K}^*$	PROG*	FAIR**	Constant*	n	R^2
ALL	.779 (14.27)	-.213 (-7.61)	-.311 (-8.05)	-1.752 (-4.12)	.298 (.34)	4.002 (2.75)	48	.906
2-6	1.142 (7.40)	-.783 (-4.34)	-1.134 (-5.61)	-2.056 (-.60)	.015 (1.98)	-13.52 (-.98)	22	.883
6+	.820 (8.95)	-.192 (-6.66)	-.281 (-7.02)	-1.432 (-3.00)	.717 (.63)	2.819 (1.53)	26	.916
Spann	.646 (5.31)	-.190 (3.10)	-.285 (-3.64)	-1.235 (-1.09)	-1.822 (-.53)	5.472 (1.54)	26	.856

Note = t-statistics are reported below the estimated coefficients.

*The estimated coefficient is the reported coefficient multiplied by 10^{-10}.

**The estimated coefficient is the reported coefficient multiplied by 10^{-14}.

Table 4

ESTIMATED ELASTICITY OF DEMAND

	ALL	2-6	6+	Spann
Elasticity	1.46	1.45	1.46	1.50

Table 5

FACTOR BIAS

Group	Marginal Product Ratio $\frac{\alpha L}{\beta K}$	Bias*	Factor Price Ratio**	Marginal Profit***	n	Number With Positive Marginal Profit
ALL	19.54 (3.82)	-6.73 (7.62)	18.91 (2.86)	.143 (.110)	48	45
2-6	22.60 (4.96)	-9.40 (6.73)	16.02 (2.66)	.225 (.141)	22	21
6+	20.38 (3.60)	-9.18 (7.26)	19.04 (2.94)	.136 (.096)	26	25
Spann	19.71 (4.03)	-7.55 (8.16)	17.88 (3.01)	.170 (.136)	26	24

Note = The means and their standard deviations reported in parentheses in the first three columns have been multiplied by 10^6.

*The Bias is the second term in (17).

**$(r_o - \theta T(r-1)y + \Psi(1-T)y)/(wy(1-T))$ obtained from (22) and (20).

***Marginal profit per unit of demand $((1-\eta)(1-t) + \eta(c/a_f)/p)$.

Table 6

FACTOR SHARE RATIOS AND RETURNS TO SCALE

Group	$\frac{\alpha^*}{\beta}$	Average Actual Factor Share Ratio**	Returns to Scale***
ALL	1.900	1.800 (.363)	1.597
2-6	2.230	1.561 (.333)	2.176
6+	1.957	1.757 (.336)	1.648
Spann	1.844	1.642 (.375)	1.327

*The value of α is taken from Table 3.

**Actual payments to capital divided by actual payments to labor.

***Computed by assuming that the output elasticity γ equals the output elasticity of labor multiplied by the ratio of the actual factor share of fuel to the actual factor share of labor.

Footnotes

The authors wish to thank James M. Griffin for his helpful comments on an earlier draft of this paper.

1. See [1].
2. In Courville [4], Petersen [18], and Spann [19].
3. This is a simplistic view of actual regulatory processes but it does provide a reasonable principle for regulation. Joskow [10] has considered the nature of regulatory processes and regulatory instruments, and in his view regulators are not interested in the rate of return earned by firms but are concerned with keeping "nominal prices from increasing."
4. In [13].
5. In [17, p. 167].
6. Taylor [21] presents a survey of the demand studies.
7. See Johansen [9] for a discussion of a similar production process.
8. Emery [8] has also used a process function for electrical generation in which output and fuel are linearly related.
9. The heat rate varies among firms depending on the scale of the firm, its technology, the fuel mix burned, and the percent of peak operation. The heat rate also depends on the <u>ex post</u> percentage of capacity at which the utility operates, but at this point a_f will be assumed to be independent of demand. This assumption is relaxed in Section III-C.

10. Utilities that purchase a substantial amount of power are excluded from the sample.

11. This is consistent with the empirical results reported by Nerlove [17].

12. In [5].

13. In [4].

14. The factor prices are assumed to be known in this model. This seems reasonable for the wage rate, which is usually fixed by multi-year contracts, but the factor price for fuel is less certain, at least in recent years. Most electric utilities are, however, permitted to make automatic adjustments in prices to compensate for fuel cost changes (Kendrick [11,p. 303]), so shareholders do not bear the risk of fuel cost changes except to the extent that the demand for electricity is affected.

15. With tax-deductible interest payments and no bankruptcy costs investors would always prefer that the firm be financed solely by debt. But, in reality, if the firm had 100% debt, the tax authorities would declare the bonds to be equity, eliminating the tax deduction. Furthermore, electric utility holding companies have limits on the amount of debt in their capital structure. An optimal ratio, θ, of debt to total capital will therfore be assumed. An additions to the capital stock will be financed with a proportion θ of new debt and $(1-\theta)$ of equity.

16. Short-sales are permitted but γ and δ are assumed to be bounded from below.

17. Analogous definitions of implicit prices may be made if $\tilde{v}$ is a discrete random variable or has a mixed distribution function. No homogeneity of preferences or expectations assumptions are made in the model.

18. The stock market equilibrium relationships in (7) and (8) are the same for any number of securities available in the securities market, although the market prices will depend on the opportunities available in the securities market.

19. In [6].

20. See [6], [7], [14].

21. See [7] and [14].

22. The implicit prices will be the same for all investors if, for example, the number of (linearly independent) security returns equals the number of values that $\tilde{v}$ may take on.

23. The interest rate is assumed to be independent of L.

24. The expected marginal utility $EU'(\tilde{R})$ has been scaled to equal one.

25. If the expression in (13) is multiplied by $\hat{\gamma}_i$ for investor i and summed over i, the right side is unchanged, since $\Sigma\hat{\gamma}_i = 1$. The left side is $\int_0^\infty (\sum_i \hat{\gamma}_i \rho_i(\tilde{v}))\tilde{v}d\tilde{v} = v^*$, where $\sum_i \hat{\gamma}_i \rho_i(\tilde{v})$ may be interpreted as a weighted average of the implicit prices of all investors. This term may be used in a value maximization criterion for the firm as indicated in Appendix A.

26. The interpretation of $\int_0^\infty \rho(\tilde{v})\tilde{v}d\tilde{v}$ as a market expectation is discussed by Dreze [6].

27. The expected utility of short sellers is minimized at D* and L*.

28. Pareto optimality may be demonstrated using the same approach as in Leland [14, p. p. 138]. Drèze has also considered the efficiency properties of similar models in more detail.

29. The regulatory principle of setting a price so as to eliminate monopoly rents has been suggested by Leland, as previously indicated, and by Myers [16]. In Leland's [13] model the uncertainty faced by the firm is factor price uncertainty, while in Myers' model the uncertainty appears in the form of an uncertain output price. In that model, the firm must choose its capacity and then its _ex post_ output. In contrast to the model presented here, _ex post_ output is restricted by capacity so the firm may not fulfill its obligation to satisfy _ex post_ demand. Besides being concerned with _ex ante_ monopoly profits, Myers seeks to find regulatory methods that will eliminate _ex post_ monopoly profits. He concludes that it is "improbable" that _ex post_ competitive performance will obtain. In the model presented here, the emphasis is on _ex ante_ monopoly rents and _ex post_ the firm may or may not earn monopoly rents depending on the demand that actually occurs. Myers states "...the effect of the constraint is to drive the net present value of the utility from 1486 to approximately zero, i.e., to eliminate the _ex ante_ monopoly profit. This presumably is a good thing."

30. The monopoly rents are assumed to be decreasing in p for p less than the monopoly price p_M when the firm produces efficiently. The monopoly price p_M would satisfy the shareholder preference condition

$$\frac{\partial EU(\tilde{R})}{\partial p} = \int_0^\infty \rho(\tilde{v})\tilde{v}d\tilde{v}\ (MR-(c/a_f)q'(p_M))\ (1-T) = 0$$

at a stockholders' equilibrium. Since $\int_0^\infty \rho(\tilde{v})\tilde{v}d\tilde{v} \geq 0$, all investors will prefer that the price p_M satisfy $MR(p_M)-(c/a_f)q'(p_M) = 0$.

31. One test of whether commissions follow this policy in setting rates is to determine the relationship between the book value of the utility's capital stock and its market value. For the firms in the sample the mean market value of the firms in the study exceeded the mean net book value by 19%, which seems reasonable since the net book value is likely to understate the reproduction value of the capital stock. The simple correlation coefficient between the two variables is .992, which also tends to support the view of the regulatory process presented here.

32. The comparison of the marginal profits evaluated at p* and p_M is complicated because the preferred levels of capital and labor for a monopolist and for the regulated firm will be different.

33. Meyers [16] recognizes this price anticipation effect in stating that "SMV [stock market value] depends on how investors expect the regulators to act... ."

34. In [3, p. 174].

35. In [10].

36. In this model regulatory lag may induce the firm to employ capital and labor in inefficient proportions in order to obtain a higher regulated price than would be set if it produced efficiently. Once the price is set, the firm has an incentive to attempt to produce efficiently. After the price has been set, the incentive in this case is much the same as in Klevorick's [12] model of regulatory lag, although in his model it is the threat of regulatory review in the future that affects firm behavior while in this model it is the effect on the current price that may cause inefficiencies. The regulatory lag considered by Bailey and Coleman [2] is different in the sense that it is the firm's inability to instantaneously affect price in an A-J type model that limits the substitution of capital for labor in their model.

37. In [10, p. 298].

38. See [19].

39. In [22].

40. One utility, Illinois Power, was excluded because it increased its capacity by approximately 65% during the sample year.

41. In [19].

42. This group contains 26 utilities while Spann's sample contained 24. The group will be labeled "Spann," since his criteria were used for selection. Fifteen of the 26 have sales of at least 6 billion KWH.

43. The equations in the forms stated in Section IV have heteroskedastic disturbance terms, so to eliminate this problem, the capital equations were multiplied by $K^{1.5}$ and the labor equation was multiplied by $(wL)^{1.5}$. The resulting estimated equations do not have significant heteroskedasticity problems.

44. These estimates of the elasticity of demand are biased. From the estimates b_3 of $\frac{\partial p}{\partial k}$ and b_4 of $\eta\frac{\partial p}{\partial k}$, $E(\hat{\eta})=E(b_4/b_3) = E(b_4)E(1/b_3) + \text{cov }(b_4,1/b_3)$ where E denotes expectation and $\hat{\eta}$ is the estimator of η defined by b_4/b_3. Since $(1/b_3)$ is a concave function of b_3 for b_3 negative, $E(b_4)E(1/b_3) > E(b_4)/E(b_3) = \eta^*$, where η^* is the estimate reported in Table 4. The actual covariance between b_3 and b_4 is positive, so the covariance between b_4 and $1/b_3$ is negative. The estimate of the demand elasticity reported in Table 4 may thus be an overestimate or an underestimate of the actual elasticity.

45. See [19].

46. No direct estimate of γ is produced by the regressions, but an estimate can be obtained using the mean actual factor shares for labor and fuel, which are .2666 and .2654, respectively. γ is then estimated as $\hat{\gamma} = \hat{\beta}(\frac{.2654}{.2666})$ and the estimate of the returns to scale is then $\hat{\alpha} + \hat{\beta} + \hat{\gamma}$.

47. See [17].

48. Courville works with plant data and thus avoids the aggregation problem.

49. See [20] and [15].

50. See [10, p. 308].

51. See [10, p. 305].

Appendix A

Derivation of Preferred Input Levels

The optimal levels of investment and labor are determined by differentiating optimized expected utility with respect to K and L, demonstrating that investors prefer the firm to maximize the value of its equity, and showing that the conditions in (14) and (15) imply value maximization. The investor's normalized preferences, given the price-taking assumption, are given by

$$\frac{\partial EU(\tilde{R})}{\partial K} = \int_0^{v^o} \rho(\tilde{v})\left(\frac{\partial\tilde{\Pi}}{\partial K}(1-T) + \theta T\left(\frac{\partial r}{\partial D}D+r-1\right)\right)\hat{\delta}d\tilde{v}$$

$$+ \int_{v^o}^{\infty} \rho(\tilde{v})\theta\left(\frac{\partial r}{\partial D}D+r\right)\hat{\delta}d\tilde{v} \qquad \text{(A1)}$$

$$+ \int_{v^o}^{\infty} \rho(\tilde{v})\left(\left(\frac{\partial\tilde{\Pi}}{\partial K} - \theta\left(\frac{\partial r}{\partial D}D+(r-1)\right)\right)(1-T)-\theta\right)\hat{\gamma}d\tilde{v} + r_o\frac{\partial\hat{z}}{\partial K}$$

$$\frac{\partial EU(\tilde{R})}{\partial L} = \int_0^{v^o} \rho(v)\frac{\partial\tilde{\Pi}}{\partial L}(1-T)\hat{\delta}d\tilde{v}$$

$$+ \int_{v^o}^{\infty} \rho(\tilde{v})\frac{\partial\tilde{\Pi}}{\partial L}(1-T)\hat{\gamma}d\tilde{v} + r_o\frac{\partial\hat{z}}{\partial L}, \qquad \text{(A2)}$$

where v^o satisfies $\Pi(v^o) \equiv D/(1-T) + (r-1)D$;[1] $(\hat{\ })$ denotes optimal, and

$$\frac{\partial\hat{z}}{\partial L} = (\bar{\gamma}-\hat{\gamma})\frac{\partial V}{\partial L}. \qquad \text{(A3)}$$

$$\frac{\partial\hat{z}}{\partial K} = (\bar{\gamma}-\hat{\gamma})\frac{\partial V}{\partial K} - \hat{\delta} \qquad \text{(A4)}$$

Given the price-taking assumption, the changes in the market prices V and r perceived by an investor may be predicted by differentiating (7) and (8) with respect to K and L to obtain

$$r_o\frac{\partial V}{\partial K}+(1-\theta)r_o=\int_{v^o}^{\infty}\rho(\tilde{v})[(\frac{\partial\tilde{\Pi}}{\partial K}-\theta(\frac{\partial r}{\partial D}D+(r-1)))(1-T)-\theta]d\tilde{v} \tag{A5}$$

$$\theta r_o = \int_0^{v^o}\rho(\tilde{v})\ (\frac{\partial\tilde{\Pi}}{\partial K}\ (1-T)\ +\theta T(\frac{\partial r}{\partial D}D+r-1))d\tilde{v}$$

$$+\int_{v^o}^{\infty}\rho(\tilde{v})\,\theta(\frac{\partial r}{\partial D}D+r)d\tilde{v} \tag{A6}$$

$$r_o\ \frac{\partial V}{\partial L} = \int_{v^o}^{\infty}\rho(\tilde{v})\ \frac{\partial\tilde{\Pi}}{\partial L}(1-T)d\tilde{v} \tag{A7}$$

$$0 = \int_0^{v^o}\rho(\tilde{v})\ \ \frac{\partial\tilde{\Pi}}{\partial L}\ (1-T)d\tilde{v} \tag{A8}$$

The term $(1-\theta)r_o$ in (A5) represents the proportion of a dollar of capital financed by equity, and the term θr_o in (A6) represents the proportion financed by debt. The conditions in (A5) through (A8) indicate that the marginal return from the factor inputs must equal the marginal return to bondholders from an increase in capital and the left-side is the marginal cost to bondholders from financing an additional dollar of capital. The marginal cost to equityholders resulting from an increase in capital is given by the left-side of (A5) and the marginal effect return to equityholders is given by the right-side.

Substituting (A4), (A5), and (A6) into (A1) and (A7), (A8) and (A3) into (A2) yields

$$\frac{\partial EU(\tilde{R})}{\partial K} = \hat{\gamma} r_o \frac{\partial V}{\partial K} + \hat{\delta} r_o + r_o(\bar{\gamma}-\hat{\gamma}) \frac{\partial V}{\partial K} - \hat{\delta} r_o$$

$$= \bar{\gamma} r_o \frac{\partial V}{\partial K} \tag{A9}$$

$$\frac{\partial EU(\tilde{R})}{\partial L} = \hat{\gamma} r_o \frac{\partial V}{\partial L} + r_o(\bar{\gamma}-\hat{\gamma}) \frac{\partial V}{\partial L} = \bar{\gamma} r_o \frac{\partial V}{\partial L} \tag{A10}$$

An initial shareholder ($\bar{\gamma} > 0$) will thus prefer a change in capital and labor if and only if the value of the equity of the firm is perceived to be increased by those changes. The perceived value changes will be the same for all investors given the spanning condition and the price-taking assumption. Adding (A5) and (A6) yields

$$r_o \frac{\partial V}{\partial K} = \int_0^{\infty} \rho(\tilde{v}) [\frac{\partial \tilde{\Pi}}{\partial K} (1-T) + \theta T(\frac{\partial r}{\partial D} D+r-1)-r_o] d\tilde{v} \tag{A11}$$

The left-side is the investor's perceived change in the total value of the equity of the firm which is equal to the value imputed by the investor to the marginal after-tax return from the firm. That return is equal to the change $\frac{\partial \tilde{\Pi}}{\partial K}(1-T)$ in the after-tax operating profit plus the marginal tax savings $\theta T(\frac{\partial r}{\partial D} D+r-1)$ from the interest deduction. Similarly, adding (A7) and (A8) yields

$$r_o \frac{\partial V}{\partial L} = \int_0^{\infty} \rho(\tilde{v}) \frac{\partial \tilde{\Pi}}{\partial L} (1-T)\, d\tilde{v} \tag{A12}$$

The implicit prices $\rho(\tilde{v})$ will, in general, be different for each investor, so the marginal value imputed to the marginal return will be different for different investors. With the spanning property, however, all price-taking investors will perceive exactly the same change in the total value of the firm, since the right sides of (A11) and (A12) are independent of investor characteristics. Substituting (A11) and (A12) into (A9) and (A10), respectively, yields (9) and (10).

The expressions in (11) and (12) involve the partial derivative of the heat rate which may be evaluated as

$$\frac{\partial a_f}{\partial K} = (\alpha/\gamma)h(K,L)^{1/\gamma}x^{1-1/\gamma}/K + h(K,L)^{1/\gamma}(1-1/\gamma)\frac{\partial x}{\partial K}\, x^{-1/\gamma} ,$$

where $h(K,L) = AK^{\alpha}L^{\beta}$. Since $x = h(K,L)\bar{f}^{\gamma}$, $\frac{\partial x}{\partial K} = \alpha x/K$. Substituting above yields

$$\frac{\partial a_f}{\partial K} = h(K,L)^{1/\gamma}x^{1-1/\gamma}\,(\alpha/\gamma K) + \alpha(1-1/\gamma)/K$$

$$= h(K,L)^{1/\gamma}x^{1-1/\gamma}(\alpha/K) = a_f\alpha/K.$$

Footnote for Appendix A

1. Higher levels of v are assumed to be associated with higher levels of profit, although this condition is not necessary for any of the results. Also, the density function assessed by the investor is assumed to be such that $\ell(v) = 0$ for all $v \leq v^{oo}$ where v^{oo} is the level of v below which the firm defaults on the interest payments.

Appendix B

Definitions of Variables

The definitions of the variables used in the empirical work are contained in Table B-1, so only certain measurement difficulties will be discussed here. A few of the electric utilities included in the sample have gas operations, and the value of the firm reflects the magnitude and profitability of those operations. The market value (V+D) has thus been multiplied by the ratio of the book value of net electric plant divided by the total net plant.

The determination of the effective corporate tax rate is complicated by four factors: 1) investment tax credits, 2) deferred taxes, 3) the accounting procedures followed, and 4) state and local profits taxes. Because of the differences in these factors, the actual profits tax rates paid in 1970 vary substantially, with one utility having a tax rate of $T = -.16$ reflecting tax credits received. In addition, the marginal tax rate is likely to differ from the average tax rate for a firm with the former being appropriate for factor input decisions and the latter being appropriate for valuation purposes. The tax rate that appears in the denominator of the left-sides of (19)-(21) is measured as the average 1970 tax rate paid by the utilities in the sample. The marginal tax rate is measured as the average U.S. profits tax rate for 1970 and appears in the numerators of the left-sides of (19)-(21). The magnitude of the estimates but not their signs depends on these tax specifications.

Electric utilities use inputs, such as maintenance services, to the production process for which no input data are available. The factor price of these services has been assumed to be the same as that for labor and the term wL has been measured by the "total electric department operating and maintenance expense" less fuel and purchased power expense. The labor input data available are the number of employees, and to reflect the other inputs, the number of employees has been multiplied by the ratio of the (total electric department operating and maintenance expense less fuel and purchased power expense) to (salaries and wages expense).

Another measurement issue involves the use of the market value in the left-sides of (19) and (21) and the book value on the right-sides. This is consistent with the idea of the book value as a rate base and the market value as the result of the employment of that level of capital. The two may not be equal because of fluctuations in the stock market or because the regulated price was set to yield an average market value over a time period that would equal the value of the capital stock.

Table B-1

Definitions

p	-	operating revenue/total KWH sales (revenue and KWH sales include negative "net received" KWH and negative purchase power costs)
$c/(a_f g(\varphi))$	-	expenditures for fuel and purchased power/total KWH sales divided by one minus the percentage of power lost $/g(\varphi)$.
L	-	electric department employees (part-time employees were counted as one-half full-time employee) multiplied by the ratio of (total electric department operating expenses less fuel and purchased power) to salary and wage expense
w	-	total salaries, wages, and maintenance charged to electric operations divided by L
T	-	average federal profits tax rate in 1970 ($T=.492$)
r_o	-	composite yield on long-term government bonds at the end of 1969 ($r_o=1.061$) Source: Federal Reserve Bulletin.
r	-	average of monthly yields on newly issued utility bonds, Jan.-Dec. 1969 for each of Moody's classifications Aaa, Aa, A and Baa.
μ	-	net electric plant less construction in progress/ net electric plant
V	-	market value of equity at beginning of 1970 (shares outstanding multiplied by the closing 1969 share price) multiplied by μ. Source: COMPUSTAT.
D	-	book value of long-term debt plus preferred stock at liquidating value multiplied by μ.

Table B-1 (continued)

K	-	net electric plant (book value) less construction in progress
θ	-	debt and preferred stock divided by the value of debt, equity, and preferred stock.
$:-1 + \frac{\partial r}{\partial D}D)$	-	assumed to equal to r-1.

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