To the Graduate Council:

I am submitting herewith a dissertation written by Michael A. Zimmer entitled "Cost of Capital and Regulatory Effectiveness in the Electric Utility Industry: An Empirical Analysis." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Feng-Yao Lee, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

Thesis
T76b
.Z566
cop.2

COST OF CAPITAL AND REGULATORY EFFECTIVENESS IN THE ELECTRIC UTILITY INDUSTRY: AN EMPIRICAL ANALYSIS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Michael A. Zimmer

March 1977

1315339

ACKNOWLEDGMENT

I wish to extend my thanks to each member of my dissertation committee: Dr. Errol Glustoff, Dr. Keith Phillips, Dr. Harry Johnson, Dr. Sidney Carroll and Dr. John Moore. Special thanks are extended to Dr. Feng-Yao Lee, who served as the committee chairman I am also grateful to Mr. Steve Cohn, who provided valuable assistance in the early stages of the study.

A profound debt of gratitude is owed to Dr. G. S. Maddala, who suggested the topic initially and provided patient guidance on numerous occasions.

Finally, I wish to thank Molly Zimmer for her constant support and encouragement and her unceasing willingness to sacrifice on my behalf.

ABSTRACT

An established result in the theory of the regulated firm is that an effective rate-of-return constraint induces the firm to employ large proportions of capital inputs to noncapital inputs than would be the case in the absence of the regulatory constraint. This overcapitalization, often referred to as the Averch-Johnson effect, has been the subject of several recent empirical studies of the electric utility industry. The present study adds to this body of literature. It seeks to test for the effectiveness of utility regulation in the context of a cost minimization model which includes the allowed rate of return as an explanatory variable and permits arbitrary elasticities of substitution between any pair of inputs.

The cost function is estimated first under a restriction which implies that regulation is not effective and then with no restrictions imposed. A likelihood ratio test is then employed as a test for regulatory effectiveness. Results of the test indicate that regulation was generally effective during the years 1968-1972.

An additional feature of this study is the estimation of annual capital rental prices for the firms in the sample. This entails in part estimation of the cost of capital for the electric utility industry. This is accomplished by applying the Miller-Modigliani two-stage estimation procedure to the valuation equation of the firm. In this manner annual cost of capital estimates are obtained for each of the years under investigation.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	A. Purpose of the Study	1
	B. Plan of the Study	3
	C. Implications of Effective Regulation: The Averch-Johnson Hypothesis	3
	D. Review of the Literature	6
	E. Test for Regulatory Effectiveness: Proposed Methodology and Additional Considerations	16
	F. Cost of Capital Estimation: Proposed Methodology	24
	G. Description of the Sample	26
II.	CRITICAL DISCUSSION OF THE LITERATURE	28
	A. Introduction	28
	B. Measures of Rental Price of Capital	28
	C. Empirical Methodologies and Econometric Specification	36
III.	COST OF CAPITAL ESTIMATION AND THE IMPLICIT RENTAL PRICE OF CAPITAL	44
	A. Introduction	44
	B. The Miller-Modigliani Cost of Capital Model	44
	C. Results of Estimation	49
	D. Estimated Capital Rental Prices	52
IV.	EMPIRICAL ANALYSIS OF REGULATORY EFFECTIVENESS	54
	A. Introduction	54
	B. The General Model and Choice of Functional Form	54
	C. Assumptions of the Model	57
	D. Revision of the Model	69
	E. Results of Estimation	72
	F. Likelihood Ratio Tests	75
V.	SUMMARY AND CONCLUSIONS	78
BIBLIOGRAPHY		81
APPENDIXES		89
A.	DESCRIPTION OF DATA	90

B. MEASUREMENT ERROR AND THE MILLER-MODIGLIANI TWO-STAGE ESTIMATION PROCEDURE 96

C. COMPUTED CAPITAL RENTAL PRICES FOR FIRMS INCLUDED IN THE SAMPLE, 1968-1972 99

D. SHEPHARD'S LEMMA FOR THE REGULATED FIRM: A REVISION 102

E. NONNEGATIVE RESTRICTIONS AND THE PROPERTIES OF THE GENERALIZED LEONTIEF COST FUNCTION 107

VITA 108

LIST OF TABLES

TABLE		PAGE
1.	First Stage Estimates: Equation (42); Dependent Variable $X(1 - t)/A$	50
2.	Second Stage Estimates: Equation (40); Dependent Variable $(V - tD)/A$	51
3.	Comparison of Cost of Capital and Various Average Yields	53
4.	Regional Concentration Ratios in U.S. Coal Markets, 1973	60
5.	Spearman Rank Correlation: Size and Age of Plant	65
6.	Sample Proportions in Proximity to Constant Returns to Scale	66
7.	Simple Regressions: Average Cost on Total Output	67
8.	Estimated Cost Function Parameters	73
9.	Tests for General Regulatory Effectiveness	76
A.1.	Computed Capital Rental Prices for Firms Included in the Sample, 1968-1972	100

CHAPTER I

INTRODUCTION

A. Purpose of the Study

This study will concern itself with an empirical examination of the effectiveness of rate-of-return regulation in the electric utility industry. It is characterized by the use of a production function which is "flexible" in the sense that it places few a priori restrictions on the technological parameters of the production structure for steam electric generation. Empirical analysis of the production structure provides information which may be used to assess the general effectiveness of regulation. In particular, as the discussion below will point out, the presence of an effective regulatory constraint in the profit maximizing activities of the firm is manifested in the form of certain distinct parameters and comparative static properties of the profit maximizing model.

An additional characteristic of this study is the estimation of the cost of capital for the firms in the sample over the period relevant to the analysis of regulation. In view of the fact that the cost of capital plays a fundamental role in the analysis of regulation, it is desirable to obtain estimates which reflect market assessments of the earning potential of electric utilities. Previous studies in regulation have neglected this issue, employing instead a variety of proxy variables intended to measure the minimum prospective yield on investment expected

by current and prospective owners. Discussion of these measures is deferred to the following chapter. It is worthwhile, however, to state the essence of the argument here. The firm's cost of capital must be distinguished from its implicit rental price per unit of capital. The former is but one component of the latter, which is generally written

$$P_K = B(r+d) \quad , \tag{1}$$

where B is a measure of equipment costs, d is depreciation and r is the cost of capital. As a matter of convenience the symbol r is often referred to as "the interest rate"; it is obvious, however, that this terminology is correct only in a world of certainty. Under conditions of less than perfect certainty the relevant measure is the firm's cost of capital, reflecting varying degrees of risk for the firm's different classes of securities.

In any case the implicit rental price P_K plays an important role in analysis of regulation, and the precision of its measurement depends to a great extent on accurate estimation of the cost of capital. Moreover, cost of capital estimation is in itself an interesting empirical exercise; since the cost of capital derives from the expectations of investors, it may not be estimated from observable magnitudes, but rather must be inferred from what can be observed, namely, the market values of the various securities which comprise the firm's capital structure. This study will thus entail first, cost of capital estimation and second, the use of these estimates to compute for each firm the capital rental price which will in turn be used in an econometric model

designed to assess regulatory effectiveness. A general description of the model occupies a later section of this chapter.

B. Plan of the Study

The remainder of the study is organized as follows. The present chapter contains a descriptive survey of existing empirical studies in electric utility regulation as well as a proposed methodology for empirical testing. Chapter II is a critical survey of existing studies, while Chapter III describes the results of cost of capital estimation. Chapter IV details the model used in this study and presents the results of the test for regulatory effectiveness. Chapter V is devoted to the conclusions of the study.

C. Implications of Effective Regulation: The Averch-Johnson Hypothesis

The simple static model of a profit maximizing firm subject to rate-of-return regulation was first analyzed by Averch and Johnson (1962). The firm, producing a single output with capital and labor inputs, is regulated to the extent that the earned rate of return on productive capital may not exceed a "fair" rate of return prescribed by a regulatory commission. In the static model it is assumed that the firm earns exactly the allowed rate of return; the allowed rate of return is assumed to exceed the market cost of capital but is less than the rate which the firm might earn in the absence of regulation.

The most significant conclusion of the Averch-Johnson analysis is that the effectively regulated firm maximizes profits by choosing a

capital-labor ratio which exceeds the ratio that would be chosen in the absence of regulation. A brief examination of the model illustrates the distorted choice of inputs. Let

$Q = \Phi(K,L)$ = the firm's (well-behaved) production function.

$R(Q) = R[\Phi(K,L)]$ = the firm's total revenue function.

K = the amount of capital input.

L = the amount of labor input.

P_K = the implicit rental price per unit of capital.

P_L = the unit price of labor.

s = the allowed rate of return (assumed to exceed the cost of capital).

The firm seeks to maximize profits

$$R[\Phi(K,L)] - P_L L - P_K K , \tag{2}$$

subject to the rate of return and production constraints,

$$R[\Phi(K,L)] - P_L L \leq sK \tag{3}$$

$$Q \leq \Phi(K,L) . \tag{4}$$

The Lagrangian expression is given by

$$Z = R[\Phi(K,L)] - P_L L - P_K K - \lambda\{R[\Phi(K,L)] - P_L L - sK\} - \theta\{Q - \Phi(K,L)\} . \tag{5}$$

Differentiation of (5) with respect to the choice variables Q, K and L yields the necessary conditions for profit maximization:

$$R'(1-\lambda) - \theta \leqq 0 \tag{6}$$

$$R'\Phi_K(1-\lambda) - P_K + \lambda s + \theta\Phi_K \leqq 0 \tag{7}$$

$$R'\Phi_L(1-\lambda) - P_L(1-\lambda) + \theta\Phi_L \leqq 0 \tag{8}$$

$$\theta \geqq 0,\ \lambda \geqq 0,\ Q \geqq 0,\ K \geqq 0,\ L \geqq 0 \tag{9}$$

$$\lambda\{R[\Phi(K,L)] - P_L L - sK\} = 0 \tag{10}$$

$$\theta\{Q - \Phi(K,L)\} = 0\ , \tag{11}$$

where subscripts on the symbol Φ denote partial derivatives of the production function and R' denotes the derivative of the revenue function with respect to Q.

If we assume that the problem has a solution at a positive level of output, then (6) through (8) are satisfied as equalities.[1] Substituting for θ in (7) and (8) and dividing (7) by (8) yields

$$\Phi_K/\Phi_L = P_K'/P_L\ ,$$

where $P_K' = (P_K - \lambda s)/(1-\lambda)$.

It is seen that the ratio of the marginal products is equal to the ratio of input prices (i.e., the choice of inputs is efficient) only if $\lambda = 0$

---

[1] Since Baumol and Klevorick (1970) have shown that $0 \leqq \lambda < 1$, it must be true that $\theta \neq 0$, since in (6) a zero value for θ implies $\lambda = 1$. Thus the firm will operate on its production frontier.

(i.e., only if the regulatory constraint is not binding). If $\lambda \neq 0$ then the choice of inputs is inefficient; it can be shown that the capital-labor ratio chosen in this case exceeds that which maximizes profit in the absence of regulation.[2]

This overcapitalization, often referred to as the Averch-Johnson thesis, results from an effective subsidy to capital in the form of a positive difference between the allowed rate of return and the market cost of capital. Since regulation is in terms of the rate of return on the firm's stock of productive capital, the firm will maximize its profits by using a larger capital-labor ratio than the unregulated firm.

Thus an empirical analysis of regulatory effects is effectively a test for the presence of overcapitalization. It is to this issue that the present study is addressed.

D. Review of the Literature

Despite the potential importance of the Averch-Johnson thesis for energy policy, it is only within the past two years that empirical studies have appeared. The first to appear were by Courville (1974) and Spann (1974). These were followed by Petersen (1975), Cowing (1975) and, most recently, Hayashi and Trapani (1976) and Boyes (1976).

Courville, recognizing that one implication of the Averch-Johnson model is that the ratio of the marginal products of capital and a noncapital input is less than the ratio of their respective prices,

---

[2]The interested reader is referred to Baumol and Klevorick (1970).

attempts to estimate the marginal rate of technical substitution between capital and fuel for purposes of comparison with the price ratio.

The specification chosen for estimation is a modified Cobb-Douglas production function,

$$\ln Q = \ln A + \alpha_K \ln K + \alpha_F \ln F + \alpha_L \ln L + \alpha_U U + \alpha_C C + \varepsilon \qquad (12)$$

where Q is output; K,L and F are capital labor and fuel inputs, respectively; U is a measure of capacity utilization (the ratio of output to capacity); C is capacity; ε is a random disturbance term.

In the context of this production function, the ratio of the marginal products of capital and fuel can be written as

$$\alpha_K F/\alpha_F K \ ,$$

and the test for overcapitalization may be carried out by determining the sign of the expression

$$\alpha_K F/\alpha_F K - P_K/P_F \ .$$

A negative value is taken as evidence supporting overcapitalization. Courville conducts the test by specifying the null hypothesis

$$\alpha_K F/K - \alpha_F P_K/P_F = 0 \qquad (13)$$

and the alternate hypothesis

$$\alpha_K F/K - \alpha_F P_K/P_F < 0 \ . \qquad (14)$$

His data consist of annual observations on 110 new steam-electric

generating plants for the periods 1948-50, 1951-55, 1956-59 and 1960-66. Each observation is taken from the first full year of plant operation. Estimating by single-equation ordinary least squares, Courville rejects the null hypothesis (13) in favor of the alternative hypothesis (14) for 105 of the 110 observations in the sample. He concludes that the evidence confirms the existence of overcapitalization.

The Spann study is an attempt at direct estimation of λ, the Lagrange multiplier associated with the regulatory constraint in the Averch-Johnson model. A nonzero value of λ implies that the regulatory constraint is binding, i.e., that overcapitalization is present. Using a three-input transcendental logarithmic production function and restrictions implied by the first order conditions of the Averch-Johnson model, Spann derives revenue share equations for the capital and fuel inputs:

$$S_K = b_1 + b_2 \ln K + b_3 \ln F + b_4 \ln L + \lambda Z \qquad (15)$$

$$S_F = b_5 + b_6 \ln K + b_7 \ln F + b_8 \ln L \qquad (16)$$

where, in addition to previously defined symbols, F denotes fuel; S_K and S_F represent the respective ratios of capital and fuel expenditures to total revenue R, and $Z = sK/R$, where s is the allowed rate of return.

Recognizing that (15) and (16) imply the inter-equation restriction

$$(1-\lambda)\, b_6 = b_3 ,$$

Spann uses a nonlinear search procedure to estimate (15) and (16) and

the coefficient λ. The system is estimated under the alternative restrictions

$$(1-\lambda)\ b_6 = b_3$$

and

$$b_6 = b_3 \ ,$$

which imply

$$\lambda \neq 0$$

and

$$\lambda = 0 \ ,$$

respectively. If it is determined that $\lambda \neq 0$, then overcapitalization may be inferred. Using plant level data for the period 1959-63 and firm level data for 1963, Spann is able to reject the null hypothesis $\lambda = 0$ at the .01 significance level; he concludes that regulation is effective.

Petersen bases his study on a cost minimization model with output assumed to be exogenous. Using a transcendental logarithmic cost function, he derives a cost share equation of the capital input,

$$P_K K/C = a_0 + a_1 \ln Q + a_2 (\ln Q)^2 + a_3 \ln P_K + a_4 \ln P_F + a_5 \ln P_L + a_6 \ln(s-P_K) \ , \qquad (17)$$

where all symbols are as defined before and C represents total production cost.

From the cost function Petersen derives two testable implications of the Averch-Johnson thesis, namely that the derivatives of both total cost and the capital cost share equation with respect to the allowed rate of return, s, are negative. Using ordinary least squares and estimating the cost function and equation (17) separately, he finds that these derived implications are confirmed by the statistical results. The sample consists of 56 steam generating plants which had experienced capacity increases of 50 percent or more during the period 1960-65. Observations used in estimation are taken from 1966, 1967 and 1968. The sample includes information on those states with and without regulation on a statewide basis, and on the method of rate base valuation (i.e., "fair value" versus "original cost") in each state. Dummy variables are accordingly included in the estimating equations, and it is found that in each case the "state" variable is significant while the "valuation" variable is not significant. Petersen concludes that rate of return regulation is effective and that changes in the allowed rate of return significantly affect the degree of cost inefficiency attendant to the regulatory constraint.

Cowing analyzes regulatory effectiveness through the use of a system of equations comprising a generalized quadratic specification of the regulated profit function and the derived demand equations which are obtained by the use of Hotelling's Lemma for profit functions:[3]

---

[3]Hotelling's Lemma states that, given the well-behaved profit function $P = P(q,w)$ where q is output and w is the n-dimensional vector of factor prices, the profit maximizing amount of input i is found by

$$\partial P(q,w)/\partial w_i = P_i(q,w) \ , \ i = 1, \ \ldots \ , \ n.$$

$$\pi = a + b_0 P_K + b_1 P_F + b_2 P_L + b_3 s + (1/2) b_4 P_F^2 + (1/2) b_5 P_L^2$$

$$+ (1/2) b_6) P_K^2 + (1/2) b_7) s^2 + b_8 (P_F P_L) + b_9 (P_F P_K)$$

$$+ b_{10} (P_F s) + b_{11} (P_K P_L) + b_{12} (P_L s) + b_{13} (P_K s) \qquad (18)$$

$$\partial \pi / \partial P_F = F^* = b_1 + b_4 P_F + b_8 P_L + b_9 P_K + b_{10} s \qquad (19)$$

$$\partial \pi / \partial P_L = L^* = b_2 + b_5 P_L + b_8 P_F + b_{11} P_L + b_{12} s \qquad (20)$$

$$\partial \pi / \partial P_K = K^* = b_0 + b_6 P_K + b_9 P_F + b_{11} P_L + b_{13} s \qquad (21)$$

$$\partial \pi / \partial s = b_3 + b_7 s + b_{10} P_F + b_{12} P_L + b_{13} P_K \, , \qquad (22)$$

where all symbols are as defined before and the starred notation represents profit maximizing amounts of the three inputs.

Using a revision of Hotelling's Lemma to account for the presence of the regulatory constraint, Cowing derives a nonlinear system of equations equivalent to (19)-(22); the test for general regulatory effectiveness is conducted by estimating first the nonlinear system under the restriction

$$b_3 = b_7 = b_{10} = b_{12} = b_{13} = 0 \, ,$$

and then with no restrictions imposed. The above restriction is equivalent to hypothesizing that regulation is ineffective, since it restricts all coefficients of the allowed rate of return s in the system (19)-(22) to zero. The test procedure involves a likelihood ratio test

for the restricted and unrestricted forms of the nonlinear system of equations. In addition, Cowing's methodology permits the retrieval of estimated Lagrange multipliers for each observation in the sample. Thus, in addition to the likelihood ratio test for general regulatory effectiveness, it is possible to test for effective regulation (i.e., the null hypothesis $\lambda_i = 0$) for each firm in the sample.

The data for Cowing's study are taken from 114 steam electric plants constructed between 1947 and 1965. The statistical results indicate that rate-of-return regulation is generally effective and exhibits considerable variability in effectiveness across firms and over time.

The study by Hayashi and Trapani is based on an analysis of the comparative static properties of the Averch-Johnson model. These properties, first suggested by McNicol (1973), are found in the derived demand equations of the regulated firm; they are of empirical interest because they are not identical to the analogous comparative statics of the unregulated firm. Denoting, as usual, the capital and labor inputs by K and L with respective prices P_K and P_L and denoting the allowed rate of return by s, McNicol's derived results may be summarized:

$$\frac{\partial K}{\partial P_L} < 0 \quad \frac{\partial K}{\partial P_K} = 0 \quad \frac{\partial K}{\partial s} < 0$$

$$\frac{\partial L}{\partial P_L} > 0 \quad \frac{\partial L}{\partial P_K} = 0 \quad \frac{\partial L}{\partial s} > 0 \; . \tag{23}$$

A test for regulatory effectiveness may be carried out by confirming results (23) through estimation of the derived demand equations for the

regulated firm. A simple extension of McNicol's results leads Hayashi and Trapani to analogous results for the firm's profit maximizing capital-labor ratio. These results are examined in estimated capital-labor equations for the Cobb-Douglas specification

$$K/L = \alpha_0 + \alpha_1 (P_L/P_K) + \alpha_2 t + \alpha_3 Q + \alpha_4 s , \tag{24}$$

and the CES specification

$$\ln(K/L) = \beta_0 + \beta_1 \ln(P_L/P_K) + \beta_2 t + \beta_3 Q + \beta_4 s , \tag{25}$$

where all symbols are as defined before, with Q denoting output and t denoting an index of technology.

Estimating both functional forms using ordinary least squares and firm-level data for thirty-four electric utilities from 1965 to 1969, Hayashi and Trapani conclude that the results generally support the hypothesis of regulatory effectiveness, and hence overcapitalization, for the sample period.

The most recent of the empirical studies is by Boyes; this paper is alone among those thus far presented in refuting the existence of the Averch-Johnson thesis. Boyes postulates a "regulated" profit maximizing model and a four-input constant ratio of elasticity of substitution (CRES) production function

$$Q = [\alpha_K K^{\beta} + \alpha_L L^{\gamma} + \alpha_M M^{\delta} + \alpha_F F^{\varepsilon}]^{-(1/\rho)} \cdot e^{u} ,$$

where, in addition to the usual inputs, M represents maintenance; u is a

random disturbance term.[4] The resulting derived demand equation for capital is shown to contain λ, the Lagrange multiplier associated with the regulatory constraint:

$$\ln K = [1/(1+\beta)]\ \ln(\alpha_K \beta/\rho) + [(1+\rho)/(1+\beta)]\ \ln Q$$

$$- [1/(1+\beta)]\ \ln(r/R' - \lambda(s-r)/(1-\lambda)R') \ , \qquad (26)$$

where r is the unit price of capital and R' denotes the derivative of the revenue function with respect to output. Boyes obtains an estimate of λ by estimating (26) together with the derived demand equations for maintenance, labor and fuel (which do not contain λ). A likelihood ratio test is used to determine whether λ is significantly different from zero. Estimating the set of equations for a sample of sixty steam electric plants placed in operation between 1957 and 1964, Boyes finds that the likelihood ratio test does not lead to rejection of the hypothesis $\lambda=0$; he concludes that the evidence is not supportive of the Averch-Johnson thesis.

In summary, previous studies employing a variety of production structures and testing procedures have generally concluded that the

---

[4] It should be noted that the above production function is a special case of the generalized form suggested by Hanoch (1975):

$$\sum D_i q^{-e_i d_i} x_i^{d_i} = 1$$

where q is output; x_i is the amount of factor i; D_i, e_i and d_i are parameters. Setting $e_i d_i$ equal to a constant for all i gives the CRES production function. The Cobb-Douglas and CES forms are also special cases.

evidence supports the existence of effective regulation and overcapitalization in the electric utility industry. A detailed criticism of these studies occupies the second chapter of this study.

Concern with the effects of utility regulation has provided the impetus for numerous other studies focusing on aspects of the problem which are not considered in this study. Stigler and Friedland (1962), in a study of early attempts at regulation, conclude that the price of electricity was not significantly affected by regulation. Westfield (1965) argues that regulation induces utilities to acquiesce to higher prices on new capital equipment. More recently a study by Moore (1970) is an attempt to test for the effectiveness of regulation by means of comparing input choices of investor-owned and public utilities. This requires the assumption that public firms adhere to optimization procedures identical to those of private firms. Such an assumption is difficult to accept on an a priori basis, and its verification is deemed beyond the scope of the present study; hence the Moore study does not receive direct consideration in the literature currently under review. Joskow (1974) constructs a model which assumes that the behavior of regulatory commissions is directed primarily at preventing increases in nominal electricity rates. Thus any nominal rate of return is permitted so long as the firm does not request a rate increase. On the basis of this model Joskow argues that utility regulation is effective.

Since these studies are not directly relevant to the questions currently under investigation, they are not included in the critical survey which occupies the following chapter. Instead the present study focuses on the Averch-Johnson model as outlined in the previous section.

E. Test for Regulatory Effectiveness: Proposed Methodology and Additional Considerations

The methodology proposed in this study rests on the notion that electric utilities minimize costs of production subject to the regulatory constraint as well as the constraint imposed by the production function. The firm is assumed to minimize the objective function

$$C = P_L L + P_K K + P_F F \tag{27}$$

subject to

$$R - P_L L - P_F F = sK \tag{28}$$

and

$$\Phi(K,L,F) = Q \ , \tag{29}$$

where R is revenue resulting from the sale of (exogenous) generated power Q; Φ is a twice-differentiable quasi-concave production function with positive marginal products. The production process is such that each input is necessary for production. Note that output is assumed to be exogenous; this is certainly tenable in the case of the electric utility industry. In most cases electric utilities are required to satisfy the demand for power at existing (regulated) prices. In addition it is assumed that factor prices are exogenous to the firm.[5] These

---

[5] It has been suggested that in some cases the price of fuel may exhibit a degree of endogeneity. This possibility and its implications for this study are examined in a later chapter.

assumptions suggest that estimation of the cost function (which has as explanatory variables the level of output and factor prices) is desirable as a means of studying the production structure of the electric utility industry.[6]

Furthermore, recent advances in duality theory enhance the appeal of the cost function approach.[7] The satisfaction of certain regularity conditions guarantees that a given production function implies a particular cost function, and vice versa. Every cost function in turn implies a set of derived demand equations. These may be obtained by application of Shephard's Lemma to a particular cost function.[8] Given the cost function C(Q,P) where Q is output and P is an n-dimensional vector of factor prices, Shephard's Lemma may be stated as

$$\partial C/\partial P_i = X_i \ , \ i = 1, \ \ldots \ , \ n$$

where X_i denotes the profit maximizing (cost minimizing) amount of factor i. Since the derived demand equations are obtained by differentiating the cost function, they generally do not give rise to additional unrestricted regression coefficients. Thus the inclusion of the derived demand equations with the cost function provides a means of increasing

---

[6]This is the general approach used in the previously discussed paper by Petersen (1975), as well as papers by Christensen and Green (1976) and Nerlove (1963).

[7]A lucid survey of these developments is given by Diewert (1974).

[8]See, for example, Shephard (1970). This result was also recognized by Samuelson (1947, pp. 68-69).

the efficiency of parameter estimates. This is particularly important in the case of "generalized" cost functions, which typically contain a relatively large number of regressors.[9]

The cost minimization model (24)-(26) may be used to derive a cost function of the general form

$$C = C(Q, P_L, P_F, P_K, s) \tag{30}$$

while application of Shephard's Lemma yields factor demand equations

$$K = K(Q, P_L, P_F, P_K, s) \tag{31}$$

$$F = F(Q, P_L, P_F, P_K, s) \tag{32}$$

$$L = L(Q, P_L, P_F, P_K, s) \ . \tag{33}$$

Equations (30)-(33) constitute the basis for empirical analysis. If the "regulated" cost minimization model is a meaningful explanation of the behavior of electric utilities, then the cost and factor demand equations should exhibit the general properties of equations (30)-(33). In particular the allowed rate of return, s, should appear as a significant explanatory variable in relationships explaining the firm's costs and its optimal input mix. This suggests that a suitable testing procedure consists of estimating the set of equations first as it would

---

[9]For a further discussion on this point see Christensen and Greene (1976). Another means of improving efficiency is to estimate the cost function alone from pooled cross section and time series data.

appear if the regulatory constraint were not binding (i.e., with all coefficients associated with the allowed rate of return restricted to zero) and second with no such restrictions imposed. A likelihood ratio test may then be applied as a test for general effectiveness of regulation.[10]

It is desirable that the specific functional form for the cost function (30) correspond to a production structure which places few a priori restrictions on the technological production parameters. Examination of the studies by Petersen (1975) and Spann (1974) discussed in the previous section suggests that one such form is the transcendental-logarithmic cost function developed by Christensen, Jorgenson and Lau (1971), while the production function developed by Hanoch (1975) provides a generalization of the CRES form used by Boyes (1976).[11] Still another suitable specification is Diewert's Generalized Leontief cost function.[12] The ultimate choice of functional form rests on consideration of its theoretical appeal as well as the statistical difficulties occasioned by its use.

Before proceeding it is worthwhile to assess several important characteristics of the electric generation industry. In particular, the

---

[10]It will be recalled that this is the general procedure adopted by Cowing (1975) for estimated profit functions. It has also been employed by Christensen and Greene (1976) as a means of testing for homotheticity in steam electric generation.

[11]See n. 4, Section B.

[12]See, for example, Diewert (1971).

organization of the industry into multiplant firms dictates that attention be devoted to the resulting implicit behavioral assumptions for the cost-minimizing firm. Because the arguments are inextricably bound to the concept of the firm's production function, a brief review of that concept is first in order.[13]

A complete description of the production function rests on the firm's production possibility set and the production input set. The production possibility set describes the set of input-output vectors which are technically attainable by the firm. The conventional theory of production presupposes the following axioms for the production possibility set Y:

(a) the vectors in Y are real-valued;

(b) Y has only the zero-vector in common with the nonnegative orthant;

(c) Y is closed;

(d) Y is convex;

(e) Y is characterized by "free disposal," so that if a certain set of outputs may be produced with a given set of inputs, the same collection of inputs will produce a smaller amount of any or all of the outputs.

Restricting the production possibility set to single-output vectors gives rise to the production input set, defined for a given quantity of output as the collection of all input vectors that will, under prevailing

---

[13]The following discussion is based on Glustoff (1974).

technology, produce that level of output. The production input set includes vectors of varying degrees of technical efficiency. The production function is defined in terms of the most efficient of these vectors; it is defined as the maximum quantity of output which may be obtained from any given input vector or, equivalently, the most efficient input vector in the production input set corresponding to a given level of output. The important points to note are first, that the production function is defined at the firm level and refers to the production of a single (homogenous) output, and second, that it fully reflects the technological constraints facing the firm. Technical efficiency is taken as a matter of course, and consideration of how the technical efficiency itself may be attained transcends the conventional theory of production.

The relevance of these points for the present study derives from the organization of the electric power industry into multiplant firms. Since the conventional theory of production assumes (at least implicitly) that firms consist of single plants, the crucial issue is the extent to which multiplant operation may in some sense distort the concept of the production function for power generation. As the following discussion will point out, multiplant operation in the electric power industry rests almost exclusively on technical considerations and hence poses at best a minimal threat to the validity of the production function concept.

Investigations into the economics of multiplant operation have been initiated by Scherer et al. (1975) in a study which uses interview

research techniques to delineate the factors which compel firms of various industries (not including electric power) to operate from a number of spatially dispersed plants rather than a single large plant. The authors conclude that multiplant organization generally rests on considerations of optimal lot size and inventory control, dynamic plant expansion projects, and location analysis. It remains to consider the implications of each of these for the present study.

Since electric power companies produce a commodity which is nonstorable, inventory-control decisions are of no relevance in the decision to operate multiple plants. Dynamic expansion considerations may be of some importance if the planning horizon of utility executives entails extended periods of time. Ideally under these circumstances such considerations should be recognized in attempts to model the industry. However, as Galatin (1968) points out, this produces estimation difficulties which are "formidable," even in the context of a simple Cobb-Douglas production function.[14] Consequently in a generalized specification such as that employed in this study the best that can be done is to presume that planning horizons are sufficiently short so as to effect little distortion in the production function. In fact observers of the electric utility industry generally agree that planning horizons for fossil-fuelled projects have shortened considerably during the past decade due to uncertainty over environmental legislation and the future

---

[14]See Galatin (1968, pp. 78-83).

viability of nonfossil-fuelled energy sources.[15] Thus it is reasonable to use a simple static model for the period under consideration in this study.

The remaining factor for consideration is the plant location decision. Location analysis in electric generation derives principally from expected transmission losses resulting from transporting generated power over long distances. The economies of scale in generation which emanate from single (large) plant operation may be offset by transmission losses, since losses increase with the square of generated power.[16] Hence the decision to operate multiple plants is essentially a manifestation of the technical constraints imposed by transmission network capabilities.

The implication of these remarks for this study is that the electric power industry may be said to possess a production function (at the firm level) which reasonably approximates the conventional (firm level, single plant, homogenous product) definition. Nonetheless the incorporation of a multiplant production function into a static model of cost minimization necessitates an additional assumption, namely that the firm operates its plants so as to equate marginal cost across plants for any level of output. Support for this exists in the form of a study by Westfield (1955), who investigated the operating practices of a large American utility. Westfield discovered that the firm employs a

---

[15]See, for example, McDiarmid (1976), LaBlanc and Luftig (1976) or Stich (1976).

[16]For further discussion on this point see Nerlove (1963, Appendix).

dispatcher to assign output quotas to each plant on the basis of a type of slide rule which calculates marginal cost for each plant at any level of total output. The dispatcher then assigns the given "load" to the various plants on the basis of equality among their marginal costs. Thus it is not unreasonable to assume that cost-minimizing utilities operate their plants "optimally" in the sense of equating generating costs at the margin.

F. Cost of Capital Estimation: Proposed Methodology

Estimation of the set of equations (30)-(33) requires data by firms and plants on each of the factor inputs and their unit prices as well as total production costs and the allowed rate of return. With the exception of the rental price of capital, these data are available from a variety of publications of the Federal Power Commission. In this study the rental price of capital will be estimated for each firm in the sample; as mentioned in the first section of this chapter, this entails in part the estimation of the cost of capital for the industry for each year under observation.

A suitable method for cost of capital estimation has been developed by Miller and Modigliani (1966), using a simple valuation model for the firm:

$$V = 1/r(X^e) + bG + u \tag{34}$$

where V is the total market value of the firm's outstanding securities; X^e is its expected earnings; G is an index of the rate of growth in

earnings; and u is a random disturbance term. The use of this model necessitates the assumption that electric utilities as a group constitute a "risk-equivalent" class with respect to future earnings. Equation (34) derives from the fundamental proposition that the current market value of the firm (in a given risk class) may be represented as the sum of its capitalized expected future earnings and an adjustment for current growth opportunities. The reciprocal of the estimated coefficient of expected earnings provides an estimate of the market capitalization rate for the class of firms in the sample. This capitalization rate may then be used to compute implicit capital rental prices for each firm, as shown above in equation (1).

Equation (34) cannot be estimated directly since expected earnings are not observable. This difficulty may not be corrected by resorting to observed earnings as a proxy for expected earnings, since the resulting measurement error leads to potentially serious bias in the key earnings coefficient. The procedure adopted in this study utilizes the Miller and Modigliani two-stage instrumental variable technique. In the first stage observed earnings are regressed against several "indicators" of observed earnings, which are then inserted into equation (34) for the second stage estimation. It can be shown that this procedure purges the expected earnings variable of measurement error, resulting in consistent estimates of the earnings coefficient (and hence the market capitalization rate).[17]

---

[17]Further discussion of this point is deferred to a later chapter.

Estimation by this technique requires data on market values of the securities of electric utilities, their current earnings and measures of growth, and information on the instruments used as explanatory variables in the first stage estimation. These data are available in the annual publications of Moody's Investors Services. Estimates will be obtained for each year relevant to the analysis of regulatory effectiveness.

G. Description of the Sample

A detailed discussion of the data used in the study is given in Appendix A. The purpose of this section is to describe the general characteristics of the sample.

The analysis will be confined to privately-owned utilities primarily engaged in steam electric generation from fossil-fuelled plants. Inclusion of public firms would make it necessary to justify the hypothesis that public enterprises are cost minimizers, a task which is beyond the scope of this study. Concentration on fossil-fuelled steam generation is intended to provide a sample of firms with access to reasonably homogenous production technology. The sample is a reasonable representation of the electric power industry, since private firms using fossil-fuelled technology account for about 75 percent of all generated power in the United States.

Moreover, it is reasonable to concentrate on the generation phase of the production process, since as Courville (1974) has shown, the transmission and distribution phases are probably characterized by

fixed proportions and hence offer few opportunities for factor substitution.

Empirical analysis in this study is conducted for a sample of annual observations at the firm level for sixty-two private utilities for each of the years 1968 through 1972. (A list of firms is provided in the appendix.)

The use of observations from the 1968-1972 period is motivated by a desire for recent data while recognizing that circumstances which prevailed after 1972, notably the oil embargo beginning in October, 1973, and the rapid escalation of the price level, present problems for empirical analysis which are beyond the scope of this study.

CHAPTER II

CRITICAL DISCUSSION OF THE LITERATURE

A. Introduction

This chapter contains a critical appraisal of previous empirical studies of regulatory effectiveness. The first part of the discussion deals with previously used measures of the rental price of capital, while the second part is concerned with the more fundamental issues of research methodology and model specification.

B. Measures of Rental Price of Capital

The capital-intensive nature of power generation, together with the nature of rate-of-return regulation, places the unit price of productive capital in a role of fundamental importance for an empirical analysis of regulatory effects. Before discussing the measures which have been employed in previous studies it is worthwhile to describe the essential components of the rental price (or "user cost") of capital as it commonly appears in the Investment literature,

$$P_K = B \left(\frac{r(1 - tw)}{(1 - t)} + \frac{d(1 - tv)}{(1 - t)} \right) \tag{35}$$

where B is a measure of equipment costs; r is the "cost of capital"; d is the rate of depreciation on capital equipment; t is the tax rate on corporate income; w is the proportion of total capital service charges

deductible as interest for tax purposes; and v represents the proportion of replacement investment deductible as depreciation.[1]

It is seen that the "cost of capital," defined as the minimum prospective yield expected by the firm's current owners on future investment projects, is imbedded in the capital rental price.[2] Since the other components of the rental price may be measured without systematic error, it is the cost of capital which creates potential for measurement error.

In the absence of market risk the cost of capital may be measured by the prevailing rate of interest. In a world of less than perfect certainty, however, there arises a broad spectrum of securities of varying yields and degrees of risk. In such a case the firm's cost of capital is no longer a directly observable magnitude, but rather must be inferred from the values which its various securities command in the market. Under these circumstances it is not sufficient to infer the cost of capital solely from yields on less risky securities such as bonds, for this implicitly assumes that all changes in investors' assessments of market risk will be reflected in uniform changes in required yields for all classes of securities. There is little basis for presuming that capital markets behave in such an orderly fashion, even in so "predictable" a case as the electric utility industry.

---

[1]The definition used in this paper is taken from Jorgenson (1963). It is presumed that net capital gains on the disposal of equipment are negligible.

[2]Throughout this paper the symbol P_K is referred to as the rental price of capital, reserving for r the phrase "cost of capital."

In the following discussion it is contended that the capital rental prices employed in previous studies share the common shortcoming of reliance on relatively "less risky" security yields as cost of capital measures. In addition, questions are raised concerning the manner in which previous authors have measured other components of the rental price; indeed, two of the studies under discussion make no distinction between the rental price and the cost of capital. In any case failure to measure the rental price without systematic error leads to doubts about the validity of previous empirical results.

The capital rental price adopted by Boyes (1976) is equivalent to expression (35) above.[3] The cost of capital, r, is measured by the average yield on Moody's AAA bonds for each year of observation. The author justifies this measure by citing the annual cost of capital estimates obtained by Miller and Modigliani (1966), which were found to conform to changes in Moody's bond yields. It should be pointed out, however, that the Miller-Modigliani analysis involved a discontinuous period of only three years (1954, 1956 and 1957), a dangerously small sample from which to draw inferences about the general conformity between bond yields and the cost of capital. Moreover, there is little reason to believe that the conformity found by Miller and Modigliani can be extrapolated to other periods of time. It is likely that the 1954-57 period was one in which both series responded in similar fashion to

---

[3]In the published version of his paper Boyes does discuss topics of data measurement. The information in this discussion is taken from an unpublished version of that paper, presented at the meetings of The Econometric Society, New York, December 1973.

supply and demand forces which pervaded capital markets in general. In extending the Miller-Modigliani results to other periods of time, one must admit the possibility of changes in the tastes of investors with respect to risk-bearing or in their collective perception of market risk for the electric utility industry. As pointed out above, there is little justification for presuming that the resulting reassessment of the market values of utility bonds and stocks will be reflected in uniform changes in their respective required yields. Consequently it cannot be expected that changes in the cost of capital will be consonant with changes in bond yields during all periods of time.[4]

An additional criticism of the rental price used by Boyes centers around his assumption that certain of its other components are constant across firms. In terms of definition (35), it is assumed that d, v, B and t are constant for any cross section; thus the only component of the rental price which is allowed to vary is w, the proportion of replacement investment deductible as depreciation for tax purposes. As a result, a significant portion of the variability in the rental price is assumed away and effectively impounded into its regression coefficient in the estimating equations.[5] This procedure is not necessary, since available annual data make it possible to reasonably approximate, at the level of the firm, the various components of the rental price.

---

[4]Miller and Modigliani do not suggest that conformity should generally be observed. On the contrary, they remark that the results of their estimation may be due in part to circumstances peculiar to their sample period; see Miller and Modigliani (1966), p. 380.

[5]See equation (26), Chapter I.

Courville (1974) defines the rental price of capital for each plant as

$$P_K = r \cdot CF \cdot B \ ,$$

where r is the cost of capital, measured as the yield on Moody's AAA bonds for the year preceding the initial year of plant operation; CF is the "capital recovery factor," defined as the uniform annual payment for an annuity of forty years equivalent (at an interest rate r) to an initial outlay of one dollar; and B denotes the book value of productive plant.[6]

The use of Moody's average yield lends itself to the same criticism directed previously to the measure used by Boyes. In addition, Courville's measure does not allow for inter-firm differences in depreciation and ignores differences in tax treatments of interest and depreciation; only the book value of plant is permitted to vary within a cross section. While the manner in which P_K is measured does not affect Courville's regression results, it nonetheless plays a vital role in his test of hypothesis, since the essence of the test is a comparison of the ratio of marginal products of capital and labor with the ratio of their prices.

Petersen (1975) adopts the conventional definition of rental price:

$$P_K = B(r + d - dB/dt) \ ,$$

---

[6]It is assumed that the average life of equipment is forty years.

where B, r and d measure as before the cost of equipment, cost of capital and depreciation respectively, and dB/dt represents the rate of change of equipment prices (presumably an index of capital gains on the disposal of equipment); differences in tax treatment are ignored. The firm's cost of capital is permitted to vary according to the rating of its bonds. The specific measure chosen is the average yield for bonds in the firm's rating class.[7] Since Petersen assumes that depreciation and equipment price changes are constant across firms, he arrives at a measure of capital rental price which varies in a cross section only according to changes in bond ratings and equipment costs.

The measures adopted by Cowing (1975) and Hayashi-Trapani (1976) share two defects. First, both fail to distinguish between the rental price of capital and the cost of capital, and second, both measure the cost of capital (hence the rental price) by the interest rate on the firm's bond issue immediately preceding the period of observation.

Ignoring the distinction between the cost of capital and the rental price of capital tacitly assumes that equipment costs, depreciation and tax treatments are constant across firms and over time. This assumption is tenuous at best, particularly as it regards the cost of productive equipment. Measuring the firm's cost of capital by the interest rate on recent debt issues offers the advantage of a measure

---

[7]The ratings and average yields are taken from Moody's publications. It should be mentioned that the information in the above discussion does not appear in the published version of Petersen's paper. The cooperation of Prof. Petersen in providing the information, as well as other helpful comments, is gratefully acknowledged.

which is specific to each firm in the sample. However, the use of yield on less-risky securities invites criticisms similar to those addressed to the previously discussed measures. Moreover, the common practice of using a single cost of capital measure for all electric utilities in a given cross section is defensible in view of available evidence (for years preceding 1973) and the prevailing consensus of industry observers.[8] Thus it is doubtful whether substantial improvements result from the use of firm-specific cost of capital measures; in any case failure to recognize the remaining components of capital rental price casts some doubt on the validity of the measures employed in these two papers.

The final rental price measure for discussion, used by Spann (1974), is equivalent to definition (35) above:

$$P_K = B \left(\frac{r(1 - tw)}{(1 - t)} + d\right)$$

where all symbols are as defined before.[9] Since it is assumed that r, d, t and w are constant across firms, only the cost of equipment is permitted to vary in any cross section of observations. In this respect Spann's measure warrants criticisms similar to those pertaining to

---

[8]See, for example, McDonald (1971) and Myers (1972). The underlying assumption is that electric utilities comprise a "risk equivalent class." A brief discussion of this assumption and its implications for this paper is deferred to the following chapter.

[9]Note that Spann's measure differs from (35) but only in his implicit assumption that v, the proportion of total replacement deductible as depreciation, is unity. An examination of firm data indicates that this proportion, usually measured as the ratio of depreciation on the income statement to total replacement is in fact close to unity and does not vary markedly across firms.

previously discussed measures. In addition, his cost of capital measure deserves special attention. The measure chosen is r = .056, taken from estimates by Litzenberger and Rao (1971). It should be noted that Litzenberger and Rao, using a valuation model for electric utility shares, drew their sample from the period 1960-66, while Spann's sample is taken from the years 1959-63. The fact that these are overlapping periods is not in itself sufficient justification for assuming that the Litzenberger-Rao results may be applied to the 1959-63 period. In addition, Spann uses this measure for each of the years in his sample; this implicitly assumes that conditions of market risk as perceived by investors were unchanging during this period. There is little evidence to support this hypothesis.

The arguments advanced in this section suggest that there are two grounds on which the capital rental prices of previous studies may be criticized. On one hand these measures have been unduly oversimplified through the restriction of various components of the rental price to constant values; on the other hand the measures generally exhibit a reliance on bond yields as measures of the cost of capital. With respect to the first problem, a simple expedient suggests itself: more detailed data are available by firm and these may be utilized to attain superior measurement. With respect to the second point, it should first be recognized that for purposes of empirical analysis the fundamental issue is whether there exists a stable positive relationship between bond yields and the cost of capital. If such a relationship exists, then empirical needs are sufficiently well served by the use of yields

on bonds. It is the contention of this study, however, that such a relationship may not exist at every point in time. In particular it is argued that circumstances affecting the electric utility industry which evolved during the period used for this study (1968-1972) produced uncertainties which may have disrupted existing relationships between yields on different classes of securities. During this period there was a growing concern about inflation, particularly with respect to rising prices of increasingly scarce fuels. This period also witnessed the burgeoning consumer and environmental movements, resulting in legislation directed in part at the electric utility industry. It is likely that these changes induced investors to reassess the earning potential of the industry; and it is unlikely that the resulting adjustment in required yields was uniform across all classes of securities.

For these reasons this study will not involve the use of bond yields as measures of the cost of capital. Instead annual estimates for the period 1968-1972 will be obtained from published information on utility earnings and the market values of electric utility securities.

C. Empirical Methodologies and Econometric Specification

It was noted in the previous chapter that the studies under discussion have employed a variety of procedures to test for regulatory effectiveness. The purpose of this section is to elucidate their major shortcomings and to suggest possible improvements in methodology.

The first studies for consideration are those by Spann (1974) and Boyes (1976). It will be recalled that in each case the testing

procedure involves the estimation of the Lagrange multiplier associated with the firm's regulatory constraint. In Spann's model the Lagrange multiplier is isolated in a revenue share equation for capital, while in Boyes's model it is shown to appear in the firm's demand equation for productive capital. The basic objection to this procedure is that the Lagrange multiplier is not a parameter to be estimated but rather a variable quantity across firms in the sample. Although strictly speaking the Lagrange multiplier is not chosen by the firm in its attempts to maximize profits, it is nonetheless determined simultaneously with the choice variables in the model. Failure to treat it in this manner constitutes an error of specification and produces results of questionable validity.

In addition, the model used in each study rests on restrictive assumptions which could be eliminated by the use of alternative testing procedures. The capital demand equation estimated by Boyes includes the derivative with respect to output of the firm's revenue function.[10] This necessitates a restriction on the revenue function; although Boyes does not discuss this point, presumably the necessary restriction is that the derivative of the revenue function (marginal revenue) is positive for all levels of output. But since the position of an electric utility approximates that of a monopolist, this restriction is equivalent to assuming that the firm's demand curve is price-elastic for all levels of output. It is unlikely that this is the general experience of firms in the electric power industry.

---

[10] See equation (26), Chapter I.

The revenue share equation estimated by Spann[11] depends critically on the assumption that the firm's demand curve exhibits constant price elasticity of demand. But this class of demand functions includes a special case, that in which demand is represented by a rectangular hyperbola, which is troublesome for Spann's model. In this case total revenue is constant and hence marginal revenue is zero for all levels of output. It is easy to show that a monopolist producing under these conditions maximizes profits by producing an infinitesimal amount of output, a result clearly incompatible with conditions in the electric power industry.

As a final point on the Spann study, it should be noted that the revenue share equation for capital includes as explanatory variables the levels of factor inputs. But these are endogenous variables in the profit maximizing model, and Spann's failure to estimate the share equation as part of a larger system of equations explaining input choices is likely to induce simultaneous equation bias in the estimates. Thus the result of his single equation estimation are subject to question.

The model developed by Courville (1974) involves single equation estimation of a modified Cobb-Douglas production function.[12] The most important objection is that the model, like that of Spann, includes

---

[11]See equation (15), Chapter I.

[12]See equation (12), Chapter I.

endogenous variables (factor inputs) as explanatory variables in a single equation context; but recent developments in the estimation of Cobb-Douglas production functions have generally followed Marschak and Andrews (1944) in specifying that the production function disturbance is "transmitted" to the factor inputs, so that the inputs are not independent of the disturbance.[13] The proper procedure would entail estimation of the production function as one of a system of equations explaining the level of output and the optimal input mix. As Mundlak and Hoch (1965) have shown, ordinary least squares estimates of this system are consistent only under certain restrictive assumptions regarding the variances and covariances of all the disturbances in the system. In any case Courville's procedure does not reflect the current state of the art in production function estimation, and it is unlikely that his results are free of simultaneous equation bias. Furthermore, problems of simultaneity are aggravated by the use of a capacity utilization measure, i.e., the ratio of output to capacity, which leaves the model with the stochastic variable output on both sides of the equation.

An additional problem with Courville's model is that it does not explicitly include regulatory variables; thus the parameter estimates are likely to reflect specification bias in the presence of an effective regulatory constraint. These points taken together cast doubts on the reliability of Courville's estimates as well as his test for overcapitalization.

---

[13] For an elaboration on this point, see Hoch (1958) or Walters (1963). Further refinements are found in Zellner, Kmenta and Dréze (1966).

The basic problem with the study by Hayashi and Trapani (1976) is that the capital-labor ratio equations do not include the price of fuel.[14] This reflects the authors' assumption that the firm's choice of capital and labor is independent of the price of fuel. In view of numerous studies which have elicited evidence of capital-fuel substitution in electric power generation,[15] this constitutes a specification error of considerable proportions, and it undermines the validity of the test for regulatory effectiveness.

The cost function specification used by Petersen (1975) represents an improvement over those of the previously discussed studies; however, the model is not specified in a manner which is fully consistent with the Averch-Johnson model of the regulated firm. In Petersen's specification the regulatory variable is the difference between the allowed rate of return and the cost of capital.[16] The appropriate specification for the cost function permits the allowed rate of return to enter directly as the regulatory variable.[17] The specification used by Petersen requires an additional assumption, i.e., that the procedure followed by regulatory commissions is to maintain a prescribed difference between the allowed rate of return and the cost of capital. This proposition does not follow from the Averch-Johnson model.[18]

---

[14] See equations (24) and (25), Chapter I.

[15] See, for example, Dhrymes and Kurz (1964).

[16] See equation (17), Chapter I. [17] See equation (30), Chapter I.

[18] Cowing (1975) has pointed out that this specification implicitly assumes that the coefficients associated with the allowed rate of return and the cost of capital are of equal absolute magnitude, a restriction

In addition, Petersen could have improved the efficiency of his estimates by including in the model the input cost share equations and estimating these together with the cost function as a set of equations. The information contributed by the share equations would result in more efficient estimates.

The testing procedure adopted by Cowing (1975) is an improvement over the previous studies, but the assumptions implicit in his profit function specification are more restrictive than those required by alternative specifications.

In particular, the profit function specification requires the assumption that the firm's output price is exogenous. It is not clear how the problem of rate structure may be confronted in the presence of this assumption. Specifically, as Baumol and Bradford (1970) have pointed out, the profit-maximizing firm subject to a rate-of-return constraint should satisfy that constraint by setting prices in separable markets such that the percentage deviation of price from marginal cost in each market is inversely proportional to the elasticity of demand in that market. Therefore it is necessary that a model such as that used by Cowing, which relies on the assumption that output price is exogenous, should include a mechanism to deal with the possibility that electric utilities (together with their regulatory commissions) may engage in price discrimination in order to generate sufficient revenue to recover total cost or to restrict total revenue in keeping with the profit

---

which does not follow from the Averch-Johnson model. Numerous helpful comments and suggestions from Prof. Cowing are appreciated.

constraint. Cowing chooses to ignore the problem and thus implicitly assumes that rate structure is constant across firms in his sample. This assumption, however, is not supported by evidence assimilated by Kafoglis and Needy (1975) in a study using 1970 data for privately owned electric utilities. Employing computed Gini coefficients[19] as measures of the "spread" of utility rate structures, the authors demonstrate that there is considerable variability of rate structures in the electric power industry. The issue is further complicated by the use of pricing schemes within each consumer class which relate marginal prices to the level of power consumption. In any case the problem of rate structure introduces into Cowing's model a number of difficulties which must be resolved if the normalized profit function specification is to be retained.

In addition, Cowing's use of profit functions with plant level data presents the minor problem of measurement of profits at the plant level. Published data on profit contributions by plant are not available, and without such information it is not clear how profits may be accurately imputed to each plant.

These problems as well as many of the previously cited shortcomings of other studies may be circumvented by the adoption of a generalized cost specification in which the allowed rate of return enters directly as the regulatory variable. This approach rests on assumptions which are readily defensible in the case of the electric utility industry, and it

---

[19]Previous applications of Gini coefficients have been in the areas of income distribution and industrial concentration.

imposes few additional restrictions on the model of the regulated firm. For these reasons the cost function approach is implemented in this study as a device for examining regulatory effectiveness.

CHAPTER III

COST OF CAPITAL ESTIMATION AND THE IMPLICIT RENTAL PRICE OF CAPITAL

A. Introduction

This chapter is devoted to estimation of the rental price of productive capital for the firms included in the analysis of regulatory effectiveness. It was pointed out in earlier remarks that measurement of the rental price entails in part estimation of the cost of capital. The following sections of this chapter are addressed, respectively, to a description of the model to be used in cost of capital estimation, the results obtained from this model for the sample under investigation, and the use of these estimates to calculate capital rental prices for each firm in the sample.

B. The Miller-Modigliani Cost of Capital Model

At the heart of the Miller-Modigliani (1966) model is the proposition that the current market value of a firm in a given "risk class" may be expressed as the capitalized value of its expected earnings:

$$V = \frac{1}{r} X^e \tag{36}$$

where V is the value of the firm (measured as the sum of its common and preferred stock and outstanding debt at current market values); X^e denotes its expected future earnings; and r is the market capitalization rate for all firms in the risk class.

It is worthwhile to reflect on the practice of categorizing a set of firms as a risk class. As a purely theoretical matter the term "risk-equivalent class" refers to a collection of firms in which the future earnings stream of each firm is perfectly correlated with that of every other firm in the class. For empirical purposes the concept may be approximated by the selection of firms which are reasonably homogenous with respect to operating risk. It is assumed that the firms presently under examination comprise such a sample.[1]

When the valuation equation is extended to recognize the existence of corporate income taxes and the deductibility of interest payments, the expression becomes

$$V = \frac{1}{r}\left(X^{e}(1 - t)\right) + tD \ , \qquad (37)$$

where t is the tax rate on corporate income, D is the dollar amount of the firm's outstanding debt, and all other variables are as defined before. Expression (37) states that the firm is effectively subsidized by the government when it uses debt as a source of funds; the subsidy is

---

[1]Originally one of the objectives of this study was to relax the risk-equivalent assumption and estimate the cost of capital accordingly. The general reasoning would have been as follows: relaxing the risk assumption, the firm's valuation equation is modified:

$$V = \frac{1}{r}\left(X^{e} - \lambda R\right) \ ,$$

where V, r and X^{e} are as defined before, R is a measure of the firm's risk and λ is constant across firms (see, for example, Schramm and Sherman, 1974). Thus heterogeneity in risk may be incorporated into the model by the inclusion of a risk variable in the valuation equation. In this study a variety of risk measures were inserted into the model, but these attempts failed to produce evidence of significant risk differences across firms. Consequently the risk homogeneity assumption is retained for the remainder of the study.

in the form of tax savings and it is measured by the product of the tax rate and the market value of debt, the latter representing the market assessment of the present value of future (tax deductible) interest payments.

An additional modification is required if allowance is to be made for the possibility that some firms in the risk class may enjoy internal investment opportunities which yield expected returns in excess of the perceived cost of capital. The approach taken in this study is to append a simple growth term to the valuation equation:

$$V = \frac{1}{r}\left(X^{e}(1 - t)\right) + tD + \beta\Delta A \ , \qquad (38)$$

where $\Delta A = \left(\frac{1}{4}(A_t - A_{t-4})/A_{t-4}\right) \cdot A_t$,

with A_t denoting the book value of total assets at time t.[2]

A final adjustment of the valuation equation is necessary in order to account for the effect of firm size on valuation. As Miller and Modigliani point out, the simplest modification is the inclusion of a constant term in the equation.[3] With this modification and with the

---

[2]This approach is used by Miller and Modigliani (1966, pp. 343-345), who point out that the firm's growth potential is the product of three elements: the profitability of future investments, the length of time during which profitable opportunities are expected to continue, and the size of future projects. The formulation in (38) implicitly assumes that the first two elements are constant across firms and that the third may be approximated by an extrapolation of the firm's past investment experience.

[3]See Miller and Modigliani (1966, pp. 347-348) for a discussion of the "size effect" on valuation.

(constant) tax subsidy tD is moved to the left hand side, the valuation equation becomes

$$(V - tD) = \beta_1 + \beta_2 X^e(1 - t) + \beta_3 \Delta A + u \ , \qquad (39)$$

where $\beta_2 = \frac{1}{r}$ and u is a random disturbance term.

Equation (39) constitutes the empirical basis for estimation of the market capitalization rate. There are, however, two impediments to the direct application of ordinary least squares to this equation. The first is that the variance of the disturbance term is not likely to be constant in a given cross section but rather is likely to depend on firm size. Application of ordinary least squares under these circumstances produces inefficient estimates.[4] This problem may be dealt with by deflating the sample observations by a measure of firm size, in this case the book value of total assets. The "weighted" regression equation then becomes

$$(V - tD)/A = \beta_1 \left(\frac{1}{A}\right) + \beta_2 \left(X^e(1 - t)/A\right) + \beta_3 (\Delta A/A) + u' \qquad (40)$$

where A denotes the book value of assets and $u' = u/A$.

A second difficulty remains, and its rectification is the essence of the Miller-Modigliani study: the expected (tax-adjusted) earnings variable is not observable and therefore must be inferred from observable magnitudes. In the Miller-Modigliani procedure it is assumed that actual

---

[4]See, for example, Kmenta (1971, pp. 253-254). In this model it is assumed that $E(u^2) = \sigma_u^2 A^2$.

and expected earnings differ by the amount of a measurement error that possesses certain stochastic properties; in addition it is recognized that certain explanatory variables relating to the firm's capital structure, dividend policy and investment behavior convey useful information about its (unobservable) expected earnings. These propositions may be expressed by the equations

$$X(1 - t)/A = X^{e}(1 - t)/A + v' \tag{41}$$

$$X^{e}(1 - t)/A = \gamma_1(1/A) + \gamma_2(\Delta A/A) + \gamma_3(D/A) + \gamma_4(P/A) + \gamma_5(CD/A) + w' \tag{42}$$

where X^{e} and X denote expected and actual earnings respectively; A and ΔA denote size and growth (as defined previously) respectively; D denotes the market value of debt; P denotes preferred stock at market value; and CD denotes common dividends. Note that equations (41) and (42) are weighted in the same manner as (40); thus $v' = v/A$ and $w' = w/A$, where v and w are the random disturbance terms for the unweighted versions of (41) and (42) respectively.

The disturbances in (40)-(42) are assumed to obey the assumptions:

$$\begin{aligned} &E(u') = E(v') = E(w') = 0 \\ &E(u'v') = E(u'w') = E(v'w') = 0 \\ &E(u')^2 = \sigma_u^2 \\ &E(v')^2 = \sigma_v^2 \\ &E(w')^2 = \sigma_w^2 \ . \end{aligned} \tag{44}$$

These propositions suggest a two-stage procedure for obtaining consistent estimates of equation (40). In the first stage actual earnings are regressed on the explanatory variables in (42). These results are used to obtain fitted values of earnings which may in turn be used as proxy observations for expected earnings in equation (40). It can be shown that subsequent estimation of the valuation equation purges expected earnings of measurement error and hence produces consistent estimates of the key earnings coefficient.[5] The reciprocal of this estimate then provides a consistent estimate of the cost of capital.[6]

C. Results of Estimation

A detailed description of the data is provided in Appendix A; it is worthwhile, however, to make several observations about the data prior to detailing the regression results. The sample consists of annual observations on sixty-two privately owned utilities for each of the years 1968 through 1972. The measure of actual tax adjusted earnings, $X(1 - t)$, is taken as the sum of current year net profits, preferred dividends and interest paid as defined and reported by the companies themselves. Measurement of the firm's current market value is a more difficult matter, since it entails the estimation of the current market price of each issue of outstanding securities. The approach taken in

---

[5] A demonstration of this point is provided in Appendix B.

[6] This result is guaranteed by a well-known theorem in statistical inference. See, for example, Kmenta (1971, p. 166).

this study is to approximate the market price by the mid-range of prices prevailing during the year.[7] Since price data on short term obligations are not available, book values must be used to approximate their market values.

It was pointed out previously that estimation proceeds in two stages. The results of the first stage (i.e., estimation of equation (42)) are presented in Table 1. They indicate that, of the explanatory variables, only the growth measure is generally not significant at the 5 percent level. These results serve as the basis for the computed earnings variable which enters the second stage (i.e., estimation of equation (40)) as a proxy for expected earnings.

TABLE 1

FIRST STAGE ESTIMATES: EQUATION (42);*
DEPENDENT VARIABLE: $X(1 - t)/A$

	Size	Growth	Debt	Preferred Stock	Common Stock	
Year	$1/A \cdot 10^7$	$\Delta A/A$	D/A	P/A	CD/A	F
1972	0.029	0.031	0.066	0.039	0.904	1105.4
	(2.01)	(1.94)	(6.68)	(2.55)	(6.18)	
1971	0.044	0.001	0.064	0.060	0.835	436.9
	(2.24)	(0.01)	(3.57)	(1.17)	(4.17)	
1970	0.047	-0.007	0.050	0.108	1.028	850.3
	(3.61)	(-0.24)	(3.55)	(3.08)	(7.03)	
1969	0.046	-0.024	0.057	0.110	0.796	676.6
	(3.70)	(-0.71)	(3.86)	(2.93)	(5.31)	
1968	0.027	0.034	0.038	0.110	0.910	1035.4
	(2.83)	(1.16)	(2.92)	(3.40)	(7.78)	

*Figures in parentheses are t - ratios.

[7] Miller and Modigliani (1966) approximated market prices by the average of weekly closing prices for the final month of the year. The measure used in this study was chosen simply because it is more

The results of the second stage estimation are presented in Table 2. The cost of capital is estimated as the reciprocal of the earnings coefficient. As expected, the earnings variable computed from the first stage regression appears to wield considerable explanatory power with respect to valuation.[8]

TABLE 2

SECOND STAGE ESTIMATES: EQUATION (40);*
DEPENDENT VARIABLE: (V - tD)/A

	Computed Earnings	Size	Growth	Implicit r	
Year	X(1-t)/A	$1/A \cdot 10^7$	$\Delta A/A$	(Percent)	F
1972	13.856	-0.261	-0.391	7.22	1242.2
	(15.81)	(-1.10)	(-1.55)		
1971	13.916	-0.230	0.054	7.16	1648.2
	(15.89)	(-1.12)	(0.21)		
1970	12.491	-0.277	0.754	8.01	1336.0
	(12.72)	(-1.30)	(2.36)		
1969	15.176	-0.443	0.928	6.59	1367.6
	(14.96)	(-2.13)	(2.48)		
1968	16.588	-0.187	0.896	6.03	1059.0
	(14.21)	(-0.82)	(1.71)		

*Figures in parentheses are t - ratios.

convenient; data on price ranges are readily accessible in Moody's Public Utility Manuals. Moreover, the midrange is an unbiased (though inefficient) estimate of the mean price, and utility stock prices generally exhibit relatively narrow price ranges in any year.

[8]In view of the fact that the growth and size variables are generally not significant in the first and second stage regressions respectively, estimation was repeated with growth deleted from the first stage and size deleted from the second stage. These attempts failed to produce an appreciable change in the estimated earnings coefficients, so the original specification was retained.

It is worthwhile to compare the estimated capitalization rates in Table 2 with average yields for various classes of public utility securities during the same time period. This comparison is presented in Table 3. Along with each entry is given its percent change from the previous year.[9] The table reveals that movements in bond yields and the cost of capital do not conform for all years during the 1968-1972 period. In particular, examination of the entries for 1971 and 1972 shows that average bond yields declined while the estimated cost of capital increased slightly. It is evident from the table that this increase reflects increases in required yields on preferred and common stocks during that period. This example illustrates a major shortcoming in the use of bond yields alone as measures of the cost of capital. In addition, Table 3 reveals that during the period under consideration there appears to be no well-defined relationship between percent changes in the two series. This has special implications for empirical analysis dealing with a time series of observations.

D. Estimated Capital Rental Prices

The cost of capital estimates obtained in the previous section constitute one of the inputs in the estimation of annual rental prices

---

[9]The cost of capital estimates may appear to be low at first sight; it should be recalled, however, that they are after-tax estimates. The after-tax measure is relevant for comparison with the allowed rate of return, since regulatory commissions allow electric utilities to deduct taxes as operating expenses prior to determination of the "fair" rate of return. If it is assumed that the average debt to equity ratio in the industry is .5, then with a tax rate of .48 the corresponding before-tax cost of capital estimates for 1968 through 1972 are 8.80, 9.62, 11.69, 10.45 and 10.54 percent respectively.

of productive capital, as was pointed out previously.[10] The results of these computations are presented by firm and year in Appendix C. In the cost function estimation which follows these measures are taken as the annual unit price of capital.

TABLE 3

COMPARISON OF COST OF CAPITAL AND VARIOUS AVERAGE YIELDS*

Year	Cost of Capital	Yields: AAA Bonds	Yield: Preferred Stock	Yield: Common Stock
1972	7.22	7.46	7.54	6.07
	(+0.01)	(-3.37)	(+6.35)	(+7.05)
1971	7.16	7.72	7.09	5.67
	(-10.61)	(-7.10)	(+3.50)	(-4.55)
1970	8.01	8.31	6.85	5.94
	(+21.55)	(+16.71)	(-1.72)	(+21.72)
1969	6.59	7.12	6.97	4.88
	(+9.29)	(+14.47)	(+1.75)	(+6.78)
1968	6.03	6.22	6.85	4.57

*Source of Average Yields: Moody's. All figures are in percent terms. Figures in parentheses are percent changes from the previous year.

[10] See expression (35), Chapter II.

CHAPTER IV

EMPIRICAL ANALYSIS OF REGULATORY EFFECTIVENESS

A. Introduction

The purpose of this chapter is to describe the model which is used to test for the effectiveness of regulation and to present the results of the test for the sample in this study. It will be seen that the use of a "regulated" cost minimization model necessitates certain revisions of the econometric specification, and a portion of this chapter describes those revisions. Additional discussion is devoted to appraisal of the assumptions which are critical to the cost function specification.

B. The General Model and Choice of Functional Form

It will be recalled that the methodology set forth in the first chapter entails the estimation of the cost and factor demand equations which are derived from the regulated model of the cost-minimizing firm. The general form of the equations, written earlier in Chapter I, is

$$C = C(Q, P_F, P_K, P_L, s) \tag{30}$$

$$K = K(Q, P_F, P_K, P_L, s) \tag{31}$$

$$F = F(Q, P_F, P_K, P_L, s) \tag{32}$$

$$L = L(Q, P_F, P_K, P_L, s) \ . \tag{33}$$

The initial procedure for empirical analysis is first to select a functional form for equation (30) and then derive the corresponding forms for (31)-(33) by applying Shephard's Lemma to the cost function. The resulting set of equations constitutes the basis for econometric analysis of regulatory effectiveness.

The functional form chosen in this study is Diewert's Generalized Leontief cost function

$$C = Q[a_{FF}P_F + a_{KK}P_K + a_{LL}P_L + a_{ss}s + 2a_{FK}(P_FP_K)^{1/2} + 2a_{FL}(P_FP_L)^{1/2} + 2a_{KL}(P_KP_L)^{1/2} + 2a_{FS}(P_Fs)^{1/2} + 2a_{KS}(P_Ks)^{1/2} + 2a_{LS}(P_Ls)^{1/2}] \quad (45)$$

where all symbols are as defined before.[1] Applying Shephard's Lemma to (45) yields the factor demand equations

$$L = Q[a_{LL} + a_{FL}(P_F/P_L)^{1/2} + a_{KL}(P_K/P_L)^{1/2} + a_{LS}(s/P_L)^{1/2}] \quad (46)$$

$$F = Q[a_{FF} + a_{FK}(P_K/P_F)^{1/2} + a_{FL}(P_L/P_F)^{1/2} + a_{FS}(s/P_F)^{1/2}] \quad (47)$$

$$K = Q[a_{KK} + a_{FK}(P_F/P_K)^{1/2} + a_{KL}(P_L/P_K)^{1/2} + a_{KS}(s/P_K)^{1/2}] \quad (48)$$

where again all symbols are as previously defined. Equation (45) is a form which is well suited for empirical analysis of steam-electric

---

[1] See Diewert (1971). Other empirical applications of this form are Parks (1971) and Woodland (1975).

generation since it allows the corresponding production function to attain an arbitrary set of elasticities of substitution at a specified vector of inputs and input prices.[2] Thus the use of a "generalized" specification places no restrictions on the technology of factor substitution. This is desirable in an analysis of regulation, since it permits flexibility in factor substitution in response to changes in regulatory parameters.

Diewert (1971) has shown that under the restriction that all parameters in equation (45) are nonnegative the cost function C satisfies the following properties (to be referred to as the "well-behaved" properties):

(a) C is positive, real-valued and finite for all finite nonzero levels of output and factor prices;

(b) C is nondecreasing and left-continuous in output;

(c) C is nondecreasing and concave in factor prices for positive levels of output;

(d) C is homogenous of degree one in factor prices.

---

[2]Equation (45) describes the case in which the production function exhibits constant returns to scale. The more general case obtains when Q is replaced by h(Q), where h is a monotonic nondecreasing function of Q.

Denny (1974) demonstrates that the Generalized Leontief cost function is a special case of a still more general form

$$C = \sum_i \sum_j \left(a_{ij} P_i^{\beta\gamma} P_j^{\beta(1-\gamma)}\right)^{1/\beta} \cdot h(Q), \; h'(Q) \geq 0 \; .$$

He also demonstrates the relationship between the Generalized Leontief and conventional forms:

a) Setting $\gamma = 1/2$ and $\beta = 1$ yields the Generalized Leontief form.
b) Setting $\gamma = 1/2$ and $a_{ij} = 0$, $i \neq j$ yields the CES cost function.
c) Setting $\gamma = 1/2$, $\beta = 0$ and $a_{ij} = 0$, $i \neq j$ yields the Cobb-Douglas cost function.

However, the nonnegativity conditions required to assure these properties are unduly restrictive, since they constrain all pairs of factors to be substitutes. This is because, as Diewert (1974) has shown, the elasticity of substitution between factors i and j is of the same sign as the parameter a_{ij}; thus the restriction $a_{ij} \geq 0$, although sufficient to guarantee these properties for the cost function, precludes complementarity between factors i and j. In this study these restrictions are not imposed, and recourse will be made to certain available procedures to determine the extent to which the cost function estimated without nonnegativity restrictions still retains the well-behaved properties.[3] In any case, as Diewert has shown, the Generalized Leontief cost function provides a second order Taylor series approximation to an arbitrary twice differentiable cost function which satisfies conditions (a) through (d).[4]

C. Assumptions of the Model

The model used in this study offers the advantage that it is free of many of the restrictive assumptions that characterize previous studies of regulatory effectiveness.[5] Nonetheless considerable reliance is placed on the assumptions that generally characterize empirical analyses of cost functions, namely that the firm's level of output and factor

---

[3]Further discussion on this point is deferred to a later section of this chapter.

[4]See Diewert (1974, p. 115 and Appendix).

[5]See Chapter II, Section C.

prices are exogenous. In addition limitations of an empirical nature necessitate certain assumptions regarding the particularities of steam electric generation. A discussion of these assumptions is the subject of the present section.

The case of the electric utility industry embodies convincing arguments in favor of the assumption of exogenous output, and the assumption of exogenous unit prices of labor and capital appears equally justifiable. There may arise some question, however, with respect to the assumption that fuel prices are exogenous. This is the first point for consideration.

Most of the firms under consideration in this study utilize two or more fossil fuels in steam generation. Since prices of natural gas and oil are largely determined by forces out of the control of the firm, the crucial issue is whether the firm may exert sufficient influence on its unit price of coal to result in an average price of fuel which is endogenous to its cost minimizing activities to such an extent as to induce serious bias in estimation.

There are two respects in which the firm may effectively exert an influence on its unit price of coal. First, it is possible that some large firms may wield a degree of monopsony power in coal markets; second, firms contemplating the construction of new plants may choose locations in close proximity to sources of coal, thereby minimizing the costs of mine-to-plant transportation. Each of these points is considered in turn.

The question of market power has recently been addressed by Shrieves (1976), who has computed regional concentration ratios for 1973 data.[6] These computations are presented in Table 4, which also lists by market area the number of firms from the sample used in this study.

The buyer concentration ratio is defined for a given market area as the ratio of coal consumption by the four largest utilities to total consumption for that area. Similarly, the seller concentration ratio is defined as the ratio of coal production by the four largest coal companies to total production for that area. For some areas eight-firm ratios are also provided, and buyer ratios for the single largest firm are listed for each area.

The evidence indicates that buyer concentration ratios are moderately high while seller ratios are considerably lower in nearly every case; in most cases sellers markets appear to be characterized by only a moderate degree of oligopoly and the presence of a competitive fringe of sellers. The figures confirm on a regional basis what Gordon has asserted on a national basis:

> Thus it would appear that in coal markets a fairly large group of coal producers into which entry is relatively free, face a more concentrated group of sophisticated buyers.[7]

These conclusions are significant since, as Bain (1966) suggests, for sellers markets in which a moderate degree of seller concentration coexists with a competitive fringe of other sellers as well as the threat of entry of outside firms the results are likely to approximate

---

[6]Helpful comments from Prof. Shrieves are gratefully acknowledged.

[7]Gordon (1975, p. 69).

TABLE 4

REGIONAL CONCENTRATION RATIOS IN U.S. COAL MARKETS, 1973

Market Area	Buyer Concentration Ratio			Seller Concentration Ratio		Firms in Sample
	Largest Firm	4-Firm Ratio	8-Firm Ratio	4-Firm Ratio	8-Firm Ratio	
Northeastern	10.3	30.5	47.5	25.4	35.5	
North Atlantic	27.6	53.5	70.4	25.8	35.3	13
Ohio-Michigan	15.7	45.6	68.7	27.1	37.1	8
West Virginia	32.8	81.4		27.9	38.9	0
Central	16.9	39.2	51.3	31.5	43.0	
North Central	25.2	54.1	72.6	52.8	82.4	5
South Central	45.1	74.2	89.1	29.1	37.6	5
Indiana	21.1	57.7	80.0	30.8	43.8	4
South Atlantic	39.7	74.0	82.7	21.7	31.8	5
West Central	42.3	66.7	75.3	50.3*		12
Southwestern #1	44.4	56.1*		44.7	70.0	3
Southwestern #2	58.9	98.4		97.4*		0
Northwestern	67.9	84.9		69.8	87.2	0
North & South Dakota	25.7	78.4	91.5	56.7	87.7	0
Alabama & Mississippi	40.5	87.6		56.0	69.0	1
Colorado	67.1	86.5		57.2	75.1	1
Wyoming	47.1	95.7		82.7	100.0	0

*Based on three reporting firms.

Source: R. Shrieves, "Geographic Market Areas and Market Structure in the Bituminous Coal Industry," Appalachian Resources Project (45), University of Tennessee, 1976.

competitive selling. Moreover, the elasticity of the industry supply curve increases with the share of the competitive fringe and the degree of ease of entry.[8]

The implication of this result for the present study is that in the case where a large buyer faces a highly elastic supply curve for the good he purchases his position approximates that of a small buyer, and analysis of his market influence does not differ markedly from that of a small buyer.[9]

Thus it is argued that, in the context of the present study, moderate seller concentration ratios in regional coal markets coupled with the existence of a competitive fringe of sellers in each market and general relative ease of entry are sufficient to justify the assumption that the buying behavior of electric utilities exhibits features of competition. It is not argued that utilities exert no influence on their coal prices; it is merely contended that their monopsony power as purchasers of coal is countered by competitive forces on the selling side sufficient to attenuate the threat of endogeneity in average fuel prices.

The subject of plant location is discussed by Gordon (1975), who asserts that while it is conceivable that firms might locate plants close to sources of coal it is not clear that this would prove advantageous in terms of total production costs. For example, limitations on water supply pose a problem for firms desiring to construct plants close to abundant Western coal supplies. Also, firms wishing to locate plants

---

[8]See Bain (1966, pp. 301-304).

[9]See, for example, Bain (1966, pp. 302-304).

outside their own areas of service are likely to encounter objections on environmental grounds from inhabitants of the expansion areas. Finally, Gordon conjectures that the legal entanglements arising from attempts to construct the larger transmission networks necessitated by remote plant locations might result in construction periods comparable in length to those of current nuclear projects.[10]

Gordon summarizes the discussion:

> If favorable economics prevail, it may be preferable to locate plants nearer to fuel sources and transmit the electricity over distances longer than those of transmission from plants located within the service area. However, many problems involving the ability to find acceptable sites and reduced fuel choice flexibility potentially limit the prospects for locating plants in close proximity to a fuel source.[11]

Thus, while it is conceivable that the firm may enjoy lower coal prices as a result of judicious location of plants, the presence of numerous complex trade-offs renders doubtful whether this would effect lower production costs for delivered power. Consequently the cost minimizing firm may be expected to view remote location projects with a degree of caution.

In view of these points, the assumption that the firm's average fuel price is exogenous is retained for the present study.[12] It is not

---

[10] See Gordon (1975, p. 83).

[11] Gordon (1975, p. 84).

[12] As an additional (albeit admittedly crude) test for the effect of firm size on average fuel prices, firms in the sample were ranked and grouped according to fuel consumption. A simple one-way analysis of variance was conducted in order to test for significant fuel price differences across groups. The test failed to show significant differences for any of the years under consideration.

suggested that this assumption is well-founded for all samples nor for all periods of time. It is, however, deemed tenable for the sample presently under consideration.

Additional points for consideration concern assumptions about the process of power generation which are necessitated by the use of a generalized econometric specification. The principle constraint imposed by this methodology is that it gives rise to numerous parameters in the cost function. Consequently in the interests of efficiency in estimation the set of explanatory variables must be kept to a manageable size. In this study that set includes total output, factor prices, allowed rate of return, average age of plant, and the "interaction terms" which are characteristic of generalized specifications. It is necessary to delete such variables as machine mix and capacity utilization, while remaining cognizant of the warning of Galatin (1968), namely that deletion of these variables may lead to "serious errors of analysis" regarding the proper separation of scale economies and technological change in the production function.[13] In order to avoid these difficulties, the model used in this study does not permit scale economies to vary with output. In addition it utilizes an index of technology (average age of plant) which is neutral in terms of output and factor prices.

These procedures imply certain assumptions regarding firm behavior and changes in technology. The use of a neutral technology index relies on the assumption that technological improvements are reasonably

---

[13]See Galatin (1968, p. 1).

continuous over time and uniform across firms. The importance of this point has been stressed by Johnston (1960); if small firms use different generation processes and factor proportions than large firms, this should not be the result of small firms being on the average older than large firms and hence using methods which are not the most efficient at observed output levels for a given state of technology.[14] Johnston elaborates:

> If technical change were uniformly rapid for all size groups and if age of equipment were randomly distributed with respect to size, various ages of plant and equipment in a cross-section survey would produce discrepancies about the true cost scale line but would not essentially distort it.[15]

Thus it is desirable to determine the extent to which size of firm and age of plant are correlated for the sample firms. Accordingly, firms in the sample were ranked by size (total capacity) and age (average age of plant). From these rankings the Spearman Rank correlation coefficient was computed for each year in the sample. The results are presented in Table 5. None of the computed coefficients are significantly different from zero, indicating that size-age correlations pose no threat regarding possible distortions in the cost function.

Deletion of capacity utilization and machine mix in the cost function requires additional assumptions. It must first be assumed that capacity utilization exhibits reasonable uniformity for a given cross section; in addition, ignoring machine mix entails the assumption that

---

[14]Johnston (1960, p. 28).

[15]Johnston (1960, p. 30).

the most efficient equipment will be operated continuously in order to satisfy the "base load," and less efficient equipment will be called into use as dictated by increases in demand.[16] In fact such an operating procedure is entirely consistent with the rational pursuit of cost minimization.

TABLE 5

SPEARMAN RANK CORRELATION: SIZE AND AGE OF PLANT*

1968	1969	1970	1971	1972
.129	.090	.128	-.089	.065

*Approximate critical value at 5 percent significance: ±.305.

The assumption of constant returns to scale is tantamount to assuming that for the sample used in this study a significant portion of steam electric generation takes place in the horizontal portion of the average cost curve. That this is valid for 1970 (the middle year in the sample) is asserted by Christensen and Greene (1976), who estimate the range of power generation characterized by constant returns to scale:

> Our primary finding, then, is that the U.S. electric power industry can be characterized by substantial scale economies

[16] Galatin (1968, p. 96) points out that data necessary for error-free measurement of capacity utilization are available only until 1953. Thus even with a simpler econometric specification (in terms of parameters to be estimated) or a very large sample size it would not be possible to include that measure in the model. Galatin accordingly terminates his sample with 1953.

> at low levels of output. But the implied decreases in average cost diminish in importance for larger firms, resulting in an average cost curve which is very flat for a broad range of output. In 1955 most firms were producing in the low side of this range. By 1970, however, the bulk of U.S. electricity generation was by firms operating in the essentially flat area of the average cost curve.[17]

To verify their claim for the sample used in this study the proportion of firms operating in proximity to the estimated range of constant returns to scale was computed for each year of observation. The results are presented in Table 6, along with the approximate proportion of total power generation accounted for by firms in that range. The results indicate that significant proportions of sample firms operated in the relevant range of output during most years, and for each year a very large proportion of total power generation was produced by firms in this range.

TABLE 6

SAMPLE PROPORTIONS IN PROXIMITY TO CONSTANT RETURNS TO SCALE

	Proportion of Firms	Proportion of Output
1968	.48	.72
1969	.58	.72
1970	.64	.83
1971	.60	.79
1972	.66	.84

Additional evidence of constant returns to scale is offered by Atkinson and Halvorsen (1976). Using 1972 data in a study of interfuel

[17] Christensen and Greene (1976, p. 656).

substitution, the authors conclude that electric power generation is not characterized by increasing returns to scale at observed levels of output.

As a final check on the validity of the returns to scale assumption, simple regression equations of average cost as a function of output have been computed for each sample year. The estimates are presented in Table 7. While the estimated output coefficient is negative for all years and generally increases in absolute value over time, it is not significantly different from zero at the 5 percent level for any year under examination. These results should be interpreted with care, since there are numerous statistical difficulties attendant to the use of this simple specification. Nonetheless the hypothesis that the slope of the line is zero may not be rejected at the 5 percent level for any of the sample years.

TABLE 7

SIMPLE REGRESSIONS: AVERAGE COST ON TOTAL OUTPUT*

Year	Intercept	Output
1968	6.548	-.011
		(-.611)
1969	7.278	-.030
		(-.750)
1970	10.156	-.106
		(-1.572)
1971	11.590	-.162
		(-1.190)
1972	12.431	-.157
		(-1.184

*Figures in parentheses are t - ratios.

The foregoing discussion establishes a reasonable justification for assuming that returns to scale are essentially constant for ranges of output which dominate the sample in this study. The generalized model is specified accordingly, since this permits a reduction in the number of unknown parameters in the model.

A final point for consideration regards the possibility of regional variations in generation cost which are not explained by the generalized cost function. It would, of course, be desirable to include in the model a mechanism for detecting consistent regional influences. It should be recognized that such influences which are reflected in different fuel prices or varying degrees of elasticity of factor substitution will be detected by the generalized specification. Remaining influences could presumably be detected by the inclusion of regional dummy variables in the model; however, the computing package used in this study does not include a provision for dummy variables. Sample stratification by region also proves fruitless, since any stratification scheme results in too few observations per stratum to yield satisfactory estimates. Consequently it must be assumed that any remaining regional influences are such they effect little distortion in the hypothesized cost function.

The discussion in this section serves to clarify some of the assumptions underlying the model used in this study. In subsequent sections additional attention is devoted to the extent to which the cost function is "well behaved" in the sense that it satisfies the regularity conditions outlined in the previous section.

D. Revision of the Model

Equations (45)-(48) form the basis for empirical testing of regulatory effects. The test may be conducted by estimating first the set of equations in its present form and then under the restriction

$$a_{FS} = a_{KS} = a_{LS} = a_{SS} = 0 \ . \tag{49}$$

A likelihood ratio test may then be conducted to test for the significance of the regulatory coefficients.

There are, however, two impediments to the direct implemention of this procedure to the model described in this study. The first problem is that Shephard's Lemma is not applicable to a model which explicitly accounts for regulation by the inclusion of a rate-of-return constraint. In such a case it is necessary to adopt a modified Shephard's Lemma to account for the additional constraint. A complete derivation of this version is provided in Appendix D; the results may be summarized as

$$K = \partial C/\partial P_K \tag{50}$$

$$F = (\partial C/\partial P_F \cdot \partial C/\partial P_K)/(\partial C/\partial P_K + \partial C/\partial s) \tag{51}$$

$$L = (\partial C/\partial P_L \cdot \partial C/\partial P_K)/(\partial C/\partial P_K + \partial C/\partial s) \ . \tag{52}$$

It is necessary, therefore, to modify equations (46)-(48) in accordance with the modified Shephard's Lemma. It will be seen that this modification results in a nonlinear set of equations equivalent to (45)-(48).

The second difficulty with the procedure in this study concerns the singularity of the covariance matrix of disturbances for

equations (45)-(48). Since the dependent variable in the cost equation is a linear combination of the dependent variables in the factor demand equations, the corresponding disturbances are also collinear, resulting in a singular disturbance covariance matrix.[18] In order to insure the nonsingularity of this matrix one of the factor demand equations must be deleted from the model. In this study the equation to be removed is the labor demand equation.[19]

When these modifications are incorporated into equations (45)-(48) the model becomes

$$C/Q = a_T T + a_{KK}P_K + a_{LL}P_L + a_{FF}P_F + a_{SS}s + 2a_{KL}(P_K P_L)^{1/2} + 2a_{FK}(P_F P_K)^{1/2} + 2a_{FL}(P_F P_L)^{1/2} + 2a_{FS}(P_F s)^{1/2} + 2a_{KS}(P_K s)^{1/2} + 2a_{LS}(P_L s)^{1/2} \quad (53)$$

$$K/Q = a_{KK} + a_{FK}(P_F/P_K)^{1/2} + a_{KL}(P_L/P_K)^{1/2} + a_{KS}(s/P_K)^{1/2} \quad (54)$$

$$F/Q = [(a_{KK}a_{FF} + a_{FK}a_{FK}) + a_{KK}a_{FK}(P_K/P_F)^{1/2} + a_{FK}a_{FF}(P_F/P_K)^{1/2} + (a_{KK}a_{FL} + a_{KL}a_{FK})(P_L/P_F)^{1/2} + (a_{KK}a_{FS} + a_{KS}a_{FK})(s/P_F)^{1/2}$$

---

[18] For a discussion on this point, see Berndt and Savine (1975).

[19] Barten (1969) has shown that maximum likelihood estimates of a set of equations are invariant with respect to the equation which is deleted. Since the estimation procedure to be used in this study results in maximum likelihood estimates, the equation deleted is of no consequence so far as the parameter estimates are concerned. The only real consequence is a loss in efficiency.

$$+ (a_{KS}a_{FF} + a_{FK}a_{FS})(s/P_K)^{1/2} + (a_{KL}a_{FF} + a_{FL}a_{FK})(P_L/P_K)^{1/2}$$

$$+ (a_{KL}a_{FS} + a_{KS}a_{FL})(P_L s/P_K P_F)^{1/2} + a_{KL}(P_L P_L/P_K P_F)^{1/2}$$

$$+ a_{KS}a_{FS}(ss/P_K P_F)^{1/2}]/[(a_{KK} + a_{SS}) + a_{FK}(P_F/P_K)^{1/2}$$

$$+ a_{KL}(P_L/P_K)^{1/2} + a_{KS}(s/P_K)^{1/2} + a_{FS}(P_F/s)^{1/2} + a_{KS}(P_K/s)^{1/2}$$

$$+ a_{LS}(P_L/s)^{1/2}] \qquad (55)$$

where all symbols are as defined before and T represents the age of plant. Note that both sides of the original equations have been divided by output, so that the equations to be estimated are unit cost and factor demand equations.[20] In addition, an index of technology, measured as the average age of productive plant, has been included in the cost equation.

Equations (53)-(55) comprise the final form for the model to be estimated in testing for regulatory effectiveness. The estimating procedure employed in this study is an iterative scheme described, for example, by Eisenpress and Greenstadt (1966). It uses the Gauss-Newton

---

[20] Dividing by output offers not only convenience in estimation, but also serves as a correction for possible heteroscedasticity in the disturbance terms of each equation. Denoting the disturbance for equation j and observation k by u_{jk}, u_{jk} is assumed to obey the properties:

$$E(u_{jk}) = 0$$

$$E(u_{jk})^2 = \sigma_j{}^2 Q_k{}^2 .$$

Dividing equation j by output changes in the disturbance term to $v_{jk} = u_{jk}/Q_k$, so that

$$E(v_{jk})^2 = E(u_{jk}{}^2/Q_k{}^2) = \sigma_j{}^2 ,$$

giving equation j a homoscedastic error term.

computational method and is known to converge to maximum likelihood.[21] The results of estimation and likelihood ratio tests are discussed in the following sections.

E. Results of Estimation

Estimates of the parameters of equations (53)-(55) for a sample of 62 utilities are presented in Table 8.

While the results for years 1970 through 1972 indicate a number of significant coefficients, the results for 1968 and 1969 are less satisfactory. It will be observed that during all years there is evidence of interaction between fuel and capital inputs; in particular, the coefficient a_{FK} is significant at the 5 percent level (or nearly so) in all years, and its positive sign is evidence of the sustitutability between fuel and capital equipment in steam generation. Thus there is convincing evidence that the appropriate way to model the electric power industry is by means of a generalized model which permits flexible factor substitution. The coefficient of the rental price of capital is significant in all years, while the technology index is significant only for 1972.

Before proceeding with the likelihood ratio tests, two qualifications are in order with respect to the results in Table 8.

---

[21] The program is available in the Time Series Processor (TSP) package. Convergence criteria depend on the largest change in parameter values associated with the last iteration and the difference between the disturbance covariance matrix and an identity matrix of order equal to the number of equations. In this study the convergence criterion for changes in estimated parameter values was fixed at 10 percent.

TABLE 8

ESTIMATED COST FUNCTION PARAMETERS*

Parameter	1972	1971	1970	1969	1968
a_T	0.114	0.073	-0.035	-0.001	0.018
	(2.53)	(1.12)	(-1.47)	(-0.01)	(0.97)
a_{FF}	0.963	0.268	0.072	0.309	0.505
	(7.97)	(1.01)	(0.90)	(1.32)	(2.03)
a_{KK}	0.093	-0.187	-0.061	-0.142	-0.309
	(5.89)	(-3.36)	(-2.69)	(-3.05)	(-6.87)
a_{LL}	3.929	7.601	-4.48	0.835	-0.550
	(5.82)	(2.89)	(-3.98)	(0.57)	(-0.03)
a_{SS}	0.145	0.105	-0.205	0.051	-0.028
	(2.52)	(1.39)	(-2.60)	(0.86)	(-0.79)
a_{FK}	0.124	0.079	0.042	0.117	0.116
	(5.15)	(3.53)	(1.92)	(3.24)	(4.24)
a_{FL}	-1.560	-1.569	0.675	-0.217	-0.527
	(-5.63)	(-2.58)	(3.10)	(-0.51)	(-0.88)
a_{FS}	-0.180	0.399	-0.165	-0.033	-0.097
	(-4.30)	(2.36)	(-3.00)	(-0.70)	(-1.43)
a_{KL}	0.033	0.021	0.051	-0.013	0.317
	(0.37)	(0.21)	(0.60)	(-0.12)	(3.53)
a_{KS}	-0.116	0.021	-0.004	0.006	-0.022
	(-4.22)	(0.94)	(-0.20)	(0.25)	(-1.33)
a_{LS}	-0.042	-1.290	1.00	-0.122	0.340
	(-0.24)	(-2.18)	(3.43)	(-0.49)	(1.73)

*Figures in parentheses are t-ratios.

First, it should be recalled that one of the assumptions underlying the Averch-Johnson model of the regulated firm is that the firm earns a rate of return in excess of its market cost of capital.[22] Comparison of the cost of capital estimates (obtained in Chapter III) with earned rates of return reveals that this assumption is generally upheld with the exception of the 1970 sample; during 1970 nearly one fifth of the sample firms failed to earn rates of return in excess of the cost of capital, while the proportion is negligible for all other years. Thus the sample observations for 1970 tend to violate one of the assumptions of the model and the corresponding estimates should accordingly be viewed with a degree of caution.

A second qualification relates to the presence of negative coefficients in Table 8. It will be recalled that the Generalized Leontief cost function satisfies the well-behaved properties under the restriction that all coefficients are nonnegative. Diewert (1971) has developed a set of conditions on the sample data which are sufficient to guarantee that the cost function satisfies these properties even in the presence of negative coefficients. A description of these conditions is provided in Appendix E; a check of these conditions reveals that they are violated (i.e., that the well-behaved properties may not hold) only for a small proportion of the sample observations. Therefore it appears that the presence of negative estimated coefficients poses virtually no threat to the well-behaved properties of the cost function (and hence

---

[22] See Chapter I, Section C.

the corresponding production function) under examination in this study.

F. Likelihood Ratio Tests

It will be recalled that in order to conduct the test for general regulatory effectiveness estimation of the set of equations (53)-(55) is repeated under the restriction

$$a_{FS} = a_{KS} = a_{LS} = a_{SS} = 0 \ ,$$

and the log-likelihood statistics may be used to test the above restriction as a null hypothesis. It is well known that the quantity -2lnL, where L represents the ratio of the likelihood functions for the restricted and unrestricted models, has an approximate Chi-Square distribution with degrees of freedom equal to the number of restrictions imposed.

The results of this test are presented in Table 9. Models I and II are the restricted and unrestricted versions respectively. Comparison of the computed statistics with the tabular Chi-Square critical value reveals that the null hypothesis of ineffective regulation may be rejected at the 1 percent level for all years under observation with the exception of 1971. It is not surprising that these results are obtained for 1971. It is generally conceded that the utility industry was significantly affected by the recession of 1970, and this is substantiated by the previously discussed comparison of earned rates of return and the estimated cost of capital for that year. Consequently the recovery

TABLE 9

TESTS FOR GENERAL REGULATORY EFFECTIVENESS*

		Log Likelihood	log L	-2 log L
1972	Model I	-678.60	-11.99	23.98
	Model II	-666.61		
1971	Model I	-666.03	-0.37	0.74
	Model II	-665.66		
1970	Model I	-608.52	-15.82	31.64
	Model II	-592.70		
1969	Model I	-620.29	-8.88	17.76
	Model II	-611.41		
1968	Model I	-595.76	-19.87	39.74
	Model II	-575.89		

*Chi-Square value for 4 d.f. is 13.28 at the 1 percent significance level.

period of 1971 probably witnessed levels of earnings which were rising but well within the constraints of regulation.

Thus while these results tend to indicate a picture of general regulatory effectiveness, it may not be inferred that the regulatory constraint is binding during all periods of time. It follows that the major implication of effective regulation, namely the Averch-Johnson overcapitalization effect, draws general support but may not be operative during all periods of time.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study adds to the empirical evidence on the effectiveness of rate-of-return regulation in the electric utility industry. It represents an improvement over previous studies in this area to the extent that it rests on fewer restrictive assumptions than other studies. In addition, the generalized specification used is fully consistent with the simple static Averch-Johnson model of the regulated firm.

The main conclusion of the study is that rate-of-return regulation was effective during most years of the period 1968-1972. This is consistent with the results of previous empirical studies of utility regulation. In the context of the Averch-Johnson model, the condition that regulation is effective is sufficient to guarantee the existence of input choice inefficiency in the form of overcapitalization.[1] It follows, therefore, that the firms during the years under investigation in this study were generally characterized by overcapitalization attributable to regulatory effects.

The principal implication of this result is that the intended benefits of rate-of-return regulation are not achieved at zero cost.

---

[1] It should be noted that effective regulation is not a necessary condition for overcapitalization. Other sufficient conditions are delineated by Chenery (1952); thus, for the years in which regulation is inferred to be effective it may not be asserted that regulation provides the sole impetus for overcapitalization.

The imposition of an effective rate-of-return constraint induces the firm to choose inefficient input combinations, and these inefficiencies should be included in cost-benefit analyses of regulation. Indeed, in view of these results it is desirable to render new assessments of the benefits of utility regulation. For if regulation fails to result in increased production of power at lower prices to such an extent as to at least offset the costs of overcapitalization, then it is undesirable from the standpoint of efficient resource allocation.

This suggests that regulatory policy should be formulated to enable the utility industry to come as close as possible to efficient use of inputs. Recent proposals for regulatory reform have stopped short of advocating deregulation of the industry. Instead the focus is on revisions of the existing regulatory process designed to encourage efficiency. For example, Klevorick (1966) suggests that the allowed rate of return should not be constant but instead related to the size of the firm's capital stock. It is contended that if the maximum allowable rate of return is permitted to decrease with successive increments in the capital stock, the inefficiencies of overcapitalization are attenuated. In another proposal Sherman (1976) suggests that a policy through which noncapital inputs are subsidized while a tax is imposed on capital inputs would result in efficient input choice.

Empirical analysis in this study is based on a generalized cost function which includes the allowed rate of return as a regulatory variable and permits flexible substitution among productive factors. Statistical results give strong support to the existence of capital-fuel

substitution in power generation, indicating that it is appropriate to model the electric power industry by means of a generalized specification.

An additional conclusion of this study is that changes in the estimated cost of capital for electric utilities do not conform to changes in bond yields for all periods of time. This has implications not only for studies of regulation but also for analyses of investment behavior in the power industry.

Useful refinements in the model of the regulated firm might include a more sophisticated treatment of the role of uncertainty. This has been suggested by Peles and Stein (1976), who assert that the conclusions of the Averch-Johnson analysis are not insensitive to the manner in which uncertainty enters the model. In addition, the increasing use of fuel adjustment clauses might have significant implications for regulatory policy. Work on incorporating adjustment clauses into the Averch-Johnson model has been initiated by Atkinson and Halvorsen (1975).

There is a need to extend this line of inquiry into other areas of regulation. While it is unlikely that the methodology employed in this study has general applicability to analysis of other regulated industries, there do exist numerous viable opportunities for meaningful research.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Arditii, F. "A Simple Explanation of Basic Cost of Capital Concepts," unpublished Federal Energy Administration memo, June 25, 1975.

2. Asbury, J. G. and K. W. Costello. "Price and Availability of Western Coal in the Midwestern Electric Utility Market, 1974-1982," Argonne National Laboratory: Energy and Environmental Systems Division (October 1974).

3. Atkinson, S. E. and R. Halvorsen. "The Effects of Rate of Return Regulation and Fuel Adjustment Clauses on Input Choice in Electricity Generation," Presented at the meetings of the American Economic Association and the Econometric Society, December 29, 1975.

4. Atkinson, S. and R. Halvorsen. "Interfuel Substitution in Steam Electric Power Generation," Journal of Political Economy, Vol. 84, No. 5 (October 1976), 959-978.

5. Averch, H. and L. L. Johnson. "Behavior of the Firm Under Regulatory Constraint," American Economic Review, Vol. 52 (December 1962), 1052-1069.

6. Bailey, E. E. Economic Theory of Regulatory Constraint (Lexington, Mass.: D. C. Heath, 1973).

7. Bain, J. S. Price Theory (New York: John Wiley and Sons, Inc., 1966).

8. Barten, A. "Maximum Likelihood Estimation of a Complete System of Demand Equations," European Economic Review, Vol. 1 (Fall, 1969), 7-73.

9. Baumol, W. and D. Bradford. "Optimal Departures from Marginal Cost Pricing," American Economic Review, Vol. LX, No. 3 (June 1970), 265-283.

10. Baumol, W. and A. Klevorick. "Input Choice and Rate of Return Regulation: An Overview of the Discussion," Bell Journal of Economics and Management Science, Vol. 1 (Autumn, 1970), 162-190.

11. Berndt, E. and N. Savin. "Estimation and Hypothesis Testing in Singular Equation Systems with Autoregressive Disturbances," Econometrica, Vol. 43, No. 5-6 (September-November 1975), 937-955.

12. Berndt, E. R. and D. O. Wood. "Technology, Prices and the Derived Demand for Energy," The Review of Economics and Statistics, Vol. LVII, No. 3 (August 1975), 259-268.

13. Boyes, W. J. "An Empirical Examination of the Averch-Johnson Effect," Economic Inquiry, Vol. XIV (March 1976), 25-35.

14. Christensen, L. and W. Greene. "Economies of Scale in U.S. Electric Power Generation," Journal of Political Economy, Vol. 84, No. 4 (August 1976), 655-676.

15. Chenery, H. B. "Overcapacity and the Acceleration Principle," Econometrica, Vol. 20 (January 1952), 1-28.

16. Christensen, L. R., D. W. Jorgensen, and L. J. Lau. "Transcendental Logarithmic Production Frontiers," The Review of Economics and Statistics, Vol. 55, No. 1 (February 1973), 28-45.

17. Christensen, L. R., D. W. Jorgensen, and L. J. Lau. "Conjugate Duality and the Transcendental Logarithmic Production Function," Econometrica, Vol. 39 (July 1971), 255-256.

18. Christensen, L. R., D. W. Jorgenson, and L. J. Lau. "Transcendental Logarithmic Utility Functions," American Economic Review, Vol. LXV, No. 3 (June 1975), 367-383.

19. Courville, L. "Regulation and Efficiency in the Electric Utility Industry," Bell Journal of Economics and Management Science, Vol. 5 (Spring, 1974), 53-74.

20. Cowing, T. G. "Profit Functions and the Estimation of Regulatory Effectiveness," Presented at the winter meetings of the Econometric Society, December 28-30, 1975, Dallas.

21. Cowing, T. G. "Duality and the Estimation of a Regulated Technology," Presented at the 1976 meeting of the Western Economic Association, June 24-27, 1976, San Francisco.

22. Crockett, J. and S. Friend. "Some Estimates of the Cost of Capital to the Electric Utility Industry: 1954-57: Comment," American Economic Review, Vol. 59, No. 5 (December 1967), 1258-1267.

23. Denny, M. "The Relationship Between Functional Forms for the Production Function," Canadian Journal of Economics, Vol. VII, No. 1 (February 1974), 22-31.

24. Diewert, W. E. "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function," Journal of Political Economy, Vol. 79 (1971), 481-507.

25. Diewert, W. E. "Applications of Duality Theory," In Frontiers of Quantitative Economics, Edited by M. D. Intriligator and D. A. Kendrick (Amsterdam: North Holland, 1974).

26. Dhrymes, P. J. and M. Kurz. "Technology and Scale in Electricity Generation," Econometrica, Vol. 32 (July 1964), 278-315.

27. Eisenpress, H. and J. Greenstadt. "The Estimation of Nonlinear Econometric Systems," Econometrica, Vol. 34, No. 4 (October 1966), 851-861.

28. Elton, E. J. and M. J. Gruber. "Valuation and the Cost of Capital in Regulated Industries," Journal of Finance, Vol. 26, No. 3 (June 1971), 661-670.

29. Federal Power Commission. Statistics of Privately Owned Electric Utilities in the United States, Class A and B, Various Issues; Washington, D.C.: U.S. Government Printing Office.

30. Federal Power Commission. Steam Electric Plant Construction Costs and Annual Production Expenses, Various Issues; Washington, D.C.: U.S. Government Printing Office.

31. Galatin, M. Economies of Scale and Technological Change in Thermal Power Generation (Amsterdam: North Holland Publishing Company, 1968).

32. Glustoff, E. "Introduction to the Theory of Production" (Class notes prepared for Economics 5111-5112, University of Tennessee, 1974).

33. Gordon, M. J. "Some Estimates of the Cost of Capital to the Electric Utility Industry 1954-57: Comment," American Economic Review, Vol. 57, No. 5 (December 1967), 1267-1278.

34. Gordon, R. L. U.S. Coal and the Electric Power Industry (Washington, D.C.: Resources of the Future, Inc., 1975).

35. Hanoch, G. "Production and Demand Models with Direct or Indirect Implicit Additivity," Econometrica, Vol. 43, No. 3 (May 1975), 395-419.

36. Hanoch, G. "CRESH Production Functions," Econometrica, Vol. 39, No. 5 (September 1971), 695-712.

37. Hayashi, P. M. and J. M. Trapani. "Rate of Return Regulation and the Regulated Firm's Choice of Capital-Labor Ratio: Further Empirical Evidence on the Averch-Johnson Model," Southern Economic Journal, Vol. 42, No. 3 (January 1976), 384-398.

38. Hoch, I. "Simultaneous Equation Bias in the Context of the Cobb-Douglas Production Function," Econometrica, Vol. 26 (1958), 566-578.

39. Humphrey, D. B. and J. R. Moroney. "Substitution Among Capital, Labor and Natural Resource Products in American Manufacturing," Journal of Political Economy, Vol. 83, No. 1 (1975), 57-83.

40. Johnston, J. Statistical Cost Analysis (New York: McGraw-Hill Book Company, Inc., 1960).

41. Jorgenson, D. W. "Capital Theory and Investment Behavior," American Economic Review, Vol. 53, No. 2 (May 1963), 247-259.

42. Joskow, P. "Inflation and Environmental Concern: Structural Change in the Process of Public Utility Price Regulation," Journal of Law and Economics, Vol. 17 (October 1974), 291-327.

43. Joskow, P. L. and P. W. MacAvoy. "Regulation and the Financial Condition of the Electric Power Companies in the 1970's," American Economic Review, Vol. LXV, No. 2 (May 1975), 295-301.

44. Kafoglis, M. and C. Needy, "'Spread' in Electric Utility Rate Structures," Bell Journal of Economics and Management Science," Vol. 6, No. 1 (Spring, 1975), 377-387.

45. Klevorick, A. "The Graduated Fair Return: A Regulatory Proposal," American Economic Review, Vol. 59 (June 1966), 477-484.

46. Kmenta, J. Elements of Econometrics (New York: The Macmillan Company, 1971).

47. Lablanc, R. and M. Luftig. "What are the New Market Prospects for Raising Utility Capital?" Public Utilities Fortnightly, Vol. 97. No. 5 (February 1976), 26-33.

48. Ling, S. Economies of Scale in the Steam Electric Power Generating Industry: An Analytical Approach (Amsterdam: North Holland Publishing Company, 1964).

49. Litzenberger, R. and C. Rao. "Estimates of the Marginal Rate of Time Preference and Average Risk Aversion of Investors in Electric Utility Shares: 1960-66," Bell Journal of Economics and Management Science, Vol. 1 (Spring, 1971), 265-277.

50. Marschak, J. and W. H. Andrews. "Random Simultaneous Equations and the Theory of Production," Econometrica, Vol. 12 (1944), 143-205.

51. McDiarmid, F. J. "Return on Equity: The Key to Financial Strength and Cost of Capital," Public Utilities Fortnightly, Vol. 97, No. 5 (February 1976), 21-25.

52. McDonald, J. G. "Required Return on Public Utility Equities: A National and Regional Analysis: 1958-1969," Bell Journal of Economics and Management Science, Vol. 2, No. 1 (Autumn, 1971), 503-514.

53. McKay, D. J. "A Note on Taxation and the Averch-Johnson Effect," Unpublished manuscript, California Institute of Technology.

54. McNicol, D. L. "The Comparative Static Properties of the Theory of the Regulated Firm," Bell Journal of Economics and Management Science (Autumn, 1973), 428-453.

55. Miller, M. and F. Modigliani. "Some Estimates of the Cost of Capital to the Electric Utility Industry, 1954-57," American Economic Review, Vol. 56 (June 1966), 333-391.

56. Miller, M. and F. Modigliani. "Some Estimates of the Cost of Capital to the Electric Utility Industry 1954-57: Reply," American Economic Review, Vol. 57, No. 5 (December 1967), 1288-1300.

57. Moody's Public Utility Manual, Various Issues (Moody's Investors Services, Inc., New York).

58. Moore, T. "The Effectiveness of Regulation of Electric Utility Prices," Southern Economic Journal, Vol. 36, No. 4 (April 1970), 365-375.

59. Mundlak, Y. and I. Hoch. "Consequences of Alternative Specifications in Estimation of Cobb-Douglas Production Functions," Econometrica, Vol. 33, No. 4 (October 1965), 814-828.

60. Myers, S. C. "The Application of Finance Theory to Public Utility Rate Cases," Bell Journal of Economics and Management Science, Vol. 3 (Spring, 1972), 58-97.

61. Nerlove, M. "Returns to Scale in Electricity Supply," Measurement in Economics: Studies in Mathematical Economics and Econometrics in Memory of Yehuda Grumfeld, edited by C. F. Christ (Stanford University Press, 1963).

62. Parks, R. "Price Responsiveness of Factor Utilization in Swedish Manufacturing, 1870-1950," Review of Economics and Statistics, Vol. LIII (May 1971), 129-139.

63. Peles, Y. and J. Stein. "The Effect of Rate of Return Regulation is Highly Sensitive to the Nature of the Uncertainty," American Economic Review, Vol. 66, No. 3 (June 1976), 278-289.

64. Petersen, H. C. "An Empirical Test of Regulatory Effects," Bell Journal of Economics and Management Science, Vol. 6 (Spring, 1975), 111-126.

65. Robichek, A. A., J. G. McDonald, and R. C. Higgins. "Some Estimates of the Cost of Capital to the Electric Utility Industry 1954-57: Comment," American Economic Review, Vol. 57, No. 5 (December 1967), 1278-1288.

66. Samuelson, P. Foundations of Economic Analysis (Cambridge: Harvard University Press, 1947).

67. Scherer, F. M., A. Beckenstein, E. Kaufer, and R. Murphy. The Economics of Multiplant Operation: An International Comparisons Study (Cambridge: Harvard University Press, 1975).

68. Schramm, R. and R. Sherman. "Profit Risk Management and the Theory of the Firm," Southern Economic Journal, Vol. 40, No. 3 (January 1974), 353-363.

69. Shephard, R. W. Theory of Cost and Production Functions (Princeton, N.J.: Princeton University Press, 1970).

70. Sherman, R. "Curing Regulatory Bias in U.S. Public Utilities," Journal of Economics and Business, Vol. 29, No. 1 (Fall, 1976), 1-9.

71. Shrieves, R. "Geographic Market Areas and Market Structure in the Bituminous Coal Industry," Appalachian Resources Project (45), University of Tennessee, 1976.

72. Solomon, E. "Alternative Rate of Return Concepts and Their Implications for Utility Regulation," Bell Journal of Economics and Management Science, Vol. 1 (Spring, 1970), 65-81.

73. Spann, R. M. "Rate of Return Regulation and Efficiency in Production: An Empirical Test of the Averch-Johnson Thesis," Bell Journal of Economics and Management Science, Vol. 5 (Spring, 1974), 38-52.

74. Stich, R. "An Additional Standard for Measuring Common Equity Costs," Public Utilities Fortnightly, Vol. 97, No. 5 (February 1976), 26-39.

75. Stigler, G. and C. Friedland. "What Can Regulators Regulate: The Case of Electricity," Journal of Law and Economics, Vol. 5, No. 2 (October 1962).

76. Uzawa, H. "Duality Principles in the Theory of Cost and Production," International Economic Review, Vol. V (May 1964), 216-220.

77. Walters, A. A. "Production and Cost Functions: An Econometric Survey," Econometrica, Vol. 31, No. 1-2 (January-April 1963), 1-63.

78. Westfield, F. "Marginal Analysis, Multiplant Firms, and Business Practice: An Example," Quarterly Journal of Economics, Vol. 69 (May 1955), 253-268.

79. Westfield, F. "Regulation and Conspiracy," American Economic Review, Vol. 55, No. 3 (June 1965), 424-443.

80. Westfield, F. "Methodology of Evaluation of Regulation," American Economic Review, Vol. 61, No. 2 (May 1971), 211-217.

81. Woodland, A. "Substitution of Structures, Equipment and Labor in Canadian Production," International Economic Review, Vol. 16, No. 1 (February 1975), 171-187.

82. Zellner, A., J. Kmenta, and J. Drèze. "Specification and Estimation of Cobb-Douglas Production Function Models," Econometrica, Vol. 34, No. 4 (October 1966), 784-795.

83. Zellner, A. "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias," Journal of the American Statistical Association, Vol. 57 (June 1962), 348-358.

APPENDIXES

APPENDIX A

DESCRIPTION OF DATA

A.1. Data Used in Cost of Capital Estimation

This section describes data used in the empirical analysis of Chapter IV. Symbols written here are identical to those used in Chapter IV. All data were taken from various issues of Moody's Public Utility Manuals.

1. Tax-Adjusted Earnings: $X(1 - t)$; the sum of current year net income available to common stockholders, preferred dividends and interest paid. In cases where firms hold reserves for deferred taxes, these reserves were added to the earnings figure. This is in view of the fact that the market is cognizant of these allocations and presumably capitalizes future earnings accordingly.
2. Index of Growth: $(1/4\ (A_t - A_{t-4})/A_{t-4})\ A_t$; in this measure A_t is defined as the book value of total assets as reported on the firm's balance sheet. The choice of a four year average is somewhat arbitrary; averages ranging from two to seven years were tried, and the four year average gave a slightly better statistical fit.
3. Market Value of Debt: D; the sum of the products of the number of bonds in each issue and the market price of the issue. As

mentioned in Chapter IV, for each issue the market price is approximated by the midrange of prices prevailing during the year.

4. Market Value of Preferred Stock: P; the sum of the products of the number of shares in each issue and the market price of the issue, the latter approximated as described above.
5. Market Value of Common Stock: C; calculated in a manner similar to that of Preferred Stock.
6. Current Market Value of the Firm: V - tD; the sum of the market value of debt, preferred stock and common stock, with a deduction equal to the corporate tax rate times the market value of debt; included in the debt measure is the book value of short term debt, defined as the sum of notes payable and accounts payable as reported on the firm's balance sheet.

A.2. Data Used in Cost Function Estimation

A list of all firms in the sample is provided later in this appendix. This section describes measurement of the variables in the cost and factor demand equations, i.e., total costs, output, factor prices and amounts of factors used, the allowed rate of return and age of plant. Firm level data were taken from various issues of Statistics of Privately Owned Electric Utilities in the United States, Classes A and B; plant data were taken from Steam Electric Plant Construction Costs and Annual Production Expenses. Both are publications of the Federal Power Commission. All data are on an annual basis.

1. Total Production Costs: C; measured in millions of dollars as reported in the respective FPC publications.
2. Total Output: Q; net generation in millions of kilowatt-hours as reported in the respective FPC publications.
3. Price of Labor: P_L; the ratio of total wages and salaries to total employees. This is an annual measure in units of thousands of dollars per unit of labor.
4. Price of Fuel: P_F; measured in dollars per million BTU.
5. Price of Capital: P_K; taken from Chapter IV, the rental price of capital is measured (in thousands of dollars) as

$$P_K = B\left[\frac{r(1 - tw)}{(1 - t)} + \frac{d(1 - tv)}{(1 - t)}\right],$$

where B is the unit cost of equipment, measured as the ratio of book value of productive plant to total megawatt capacity; r is the cost of capital, estimated in Chapter IV; t is the tax rate, taken to be .48; d is the rate of depreciation on utility plant as reported by the companies themselves; w is the reported proportion of debt in the capital structure as reported by the companies; and v is the ratio of depreciation reported on the Income Statement to total depreciation and depletion of plant reported in the Sources and Applications of Funds Statement.

6. Allowed Rate of Return: s; measured as an average of the firm's current year and previous year earned rate of return on rate base; the use of averages is based on the assumption that <u>over time</u> the regulatory commission is successful in holding the firm's earnings to the allowed rate of return.

7. Capital Input: K; measured as the installed generating capacity in megawatts.
8. Labor Input: L; measured as the average total number of employees.
9. Fuel Input: F; BTU content of fuel burned.
10. Age of Plant: T; the measure used is a weighted average of plant ages, where the age of each plant is weighted by its proportion of the total megawatt generating capacity currently owned by the firm.

A.3. Sample: Privately Owned Electric Utilities

1. Alabama Power Company
2. Indiana-Kentucky Electric Corporation
3. Arkansas Power and Light Company
4. Pacific Gas and Electric Company
5. San Diego Gas and Electric Company
6. Southern California Edison Company
7. Public Service Company of Colorado
8. Connecticut Light and Power Company
9. Potomac Electric Power Company
10. Florida Power Corporation
11. Florida Power and Light Company
12. Tampa Electric Company
13. Georgia Power Company
14. Commonwealth Edison Company
15. Illinois Power Company
16. Indiana and Michigan Electric Company
17. Indianapolis Power and Light Company
18. Northern Indiana Public Service Company
19. Public Service Company of Indiana, Inc.
20. Louisville Gas and Electric Company
21. Gulf States Utilities
22. Louisiana Power and Light Company
23. New Orleans Public Service Company
24. Baltimore Gas and Electric Company
25. Boston Edison Company
26. New England Power Company
27. Consumers Power Company
28. Detroit Edison Company
29. Northern States Power Company
30. Kansas City Power and Light Company
31. Union Electric Company
32. Jersey Central Power and Light Company
33. Public Service Electric and Gas Company
34. Consolidated Edison of New York, Inc.
35. Long Island Lighting Company
36. New York State Electric and Gas Corporation
37. Niagara Mowhawk Power Corporation
38. Carolina Power and Light Company
39. Duke Power Company
40. Cincinnati Gas and Electric Company
41. Cleveland Electric Illuminating Company
42. Columbus and Southern Ohio Electric Company
43. Dayton Power and Light Company
44. Ohio Edison Company
45. Ohio Power Company
46. Oklahoma Gas and Electric Company

47. Public Service Company of Oklahoma
48. Duquesne Light Company
49. Pennsylvania Electric Company
50. Pennsylvania Power and Light Company
51. Philadelphia Electric Company
52. West Penn Power Company
53. South Carolina Electric and Gas Company
54. Central Power and Light Company
55. Dallas Power and Light Company
56. Houston Lighting and Power Company
57. Southwestern Public Service Company
58. Texas Electric Service Company
59. Texas Power and Light Company
60. Virginia Electric and Power Company
61. Appalachian Power Company
62. Wisconsin Electric Power Company

APPENDIX B

MEASUREMENT ERROR AND THE MILLER-MODIGLIANI TWO-STAGE ESTIMATION PROCEDURE

The Miller-Modigliani model may be expressed as a set of equations:

$$V = \alpha X' + \sum \beta_i Z_i + u \qquad \text{(A1)}$$

$$X = X' + v \qquad \text{(A2)}$$

$$X' = \sum \gamma_i Z_i + w \ , \qquad \text{(A3)}$$

where V denotes the market value of the firm; X' and X denote expected and actual earnings respectively; Z_i, i = 1 ... n, are other relevant variables (where some γ_i or β_i may be zero); v is the measurement error encountered in using observed earnings as a proxy for expected earnings; u and w are random disturbance terms with zero mean, constant variance and (by construction) uncorrelated with the Z_i; it is also assumed that the measurement error, v, is uncorrelated with the Z_i and has zero mean and constant variance. Finally the three error terms are assumed to be independent of each other.

The focus of the analysis is on estimation of α, the earnings coefficient in equation (A1). Clearly a necessary condition for estimates of α to be consistent is that the variable used for expected earnings must be free of measurement error as well as highly correlated with expected earnings. The purpose of this section is to show that the two stage

procedure used in this study effectively removes the measurement error.

Substituting (A3) into (A2),

$$X = \sum \gamma_i Z_i + w + v \ . \tag{A4}$$

Application of ordinary least squares to (A3) yields fitted values of earnings,

$$\hat{X} = \sum g_i Z_i \ , \tag{A5}$$

where g_i is the ordinary least squares estimate of γ_i, i = 1 ... n. Subtracting (A4) from (A5) yields

$$\hat{X} - X = \sum (g_i - \gamma_i) Z_i - v - w \ , \tag{A6}$$

so that

$$\hat{X} = X + \sum (g_i - \gamma_i) Z_i - v - w \ . \tag{A7}$$

Substituting (A2) into (A7),

$$\hat{X} = X' + \sum (g_i - \gamma_i) Z_i - w \ , \tag{A8}$$

and the error term v is eliminated. The error term w causes no difficulties with respect to consistency, since by construction it is uncorrelated with the Z_i and hence with X. Also, under the assumptions of the model, g_i is a consistent estimate of γ_i, i = 1 ... n; hence the second term on the right hand side of (A8) tends to zero as the sample size increases. Consequently in large samples the use of fitted earnings

as an instrument for expected earnings as described above removes the measurement error without introducing additional difficulties regarding consistency of the estimates.

APPENDIX C

COMPUTED CAPITAL RENTAL PRICES FOR FIRMS INCLUDED IN THE SAMPLE, 1968-1972

The rental prices listed here are computed as described in Appendix A, Section A.2. In this list firms are numbered by the same scheme found in the sample listing of (Appendix A, Section A.3). The figures may be interpreted as thousands of dollars per megawatt capacity; they are annual figures.

TABLE A.1

COMPUTED CAPITAL RENTAL PRICES FOR FIRMS INCLUDED IN THE SAMPLE, 1968-1972

Firm	1968	1969	1970	1971	1972
1	11.10	12.72	14.57	12.87	13.91
2	14.74	15.86	18.86	17.36	19.12
3	11.71	12.81	13.63	12.11	11.91
4	12.26	13.22	15.61	14.25	14.62
5	13.41	14.26	16.86	15.74	16.50
6	12.59	14.20	16.69	15.09	15.92
7	15.51	16.56	19.47	18.22	18.49
8	18.18	19.31	21.94	18.99	20.01
9	13.90	14.44	17.80	17.31	17.69
10	13.87	14.01	15.58	14.10	13.77
11	9.60	9.88	11.32	10.37	10.58
12	11.74	12.08	15.37	14.68	14.25
13	11.10	11.83	13.33	12.58	12.25
14	17.26	18.41	20.00	17.93	19.23
15	18.83	20.14	24.57	22.79	23.44
16	15.59	16.71	17.61	15.47	15.91
17	15.13	15.60	17.60	16.07	20.30
18	17.00	18.64	23.29	21.11	20.30
19	16.57	17.94	20.33	19.04	18.77
20	14.12	15.24	17.57	15.67	17.25
21	11.49	12.15	13.67	12.80	12.88
22	9.32	9.27	10.53	9.69	8.81
23	11.33	11.92	13.74	12.81	12.82
24	17.91	21.03	24.53	22.91	22.21
25	15.78	16.29	17.14	16.39	17.06
26	19.20	18.50	20.39	18.53	18.46
27	15.31	16.74	19.25	17.85	17.77
28	15.45	16.66	18.64	17.99	18.62
29	16.71	18.88	20.66	18.82	20.30
30	14.97	14.81	16.84	15.34	15.48
31	16.53	17.88	21.27	19.36	20.05
32	18.30	17.05	23.65	22.35	23.36
33	29.37	33.19	37.08	33.49	30.53
34	17.57	18.64	21.55	19.67	20.95
35	16.15	17.77	20.88	19.43	20.75
36	15.79	16.76	19.57	18.20	18.58
37	16.05	17.03	19.80	18.62	19.35
38	11.67	12.47	13.93	10.53	15.10
39	12.21	11.14	13.88	12.99	14.23
40	16.78	17.92	21.04	19.46	19.61
41	16.12	16.68	18.48	16.80	17.65

TABLE A.1 (continued

Firm	1968	1969	1970	1971	1972
42	15.81	16.73	18.11	17.23	18.04
43	15.16	15.94	19.34	18.13	18.15
44	18.66	24.36	21.94	20.51	20.17
45	14.81	15.57	16.72	15.45	16.26
46	12.77	12.39	14.34	12.23	12.43
47	12.12	12.82	13.89	13.38	12.77
48	18.30	19.37	23.35	21.32	20.99
49	16.50	17.96	19.71	18.27	18.31
50	19.41	16.75	20.28	19.26	20.53
51	21.04	23.17	28.28	32.27	27.01
52	15.64	17.31	19.28	17.92	19.43
53	14.53	13.82	17.78	15.72	15.92
54	10.99	11.40	13.02	11.98	15.50
55	9.47	10.58	11.58	12.01	12.78
56	7.49	8.84	10.20	9.25	9.11
57	13.25	14.34	17.00	15.29	8.89
58	11.18	11.55	13.43	12.69	13.43
59	8.73	9.40	13.02	10.16	10.23
60	13.76	13.67	15.65	14.20	14.09
61	14.59	15.66	16.93	16.34	16.67
62	13.76	15.16	17.13	16.58	17.53

APPENDIX D

SHEPHARD'S LEMMA FOR THE REGULATED FIRM: A REVISION

Given the cost minimization model: minimize[K, L, F]

$$C = P_L L + P_F F + P_K K$$

Subject to

$$R - P_L L - P_F F = sK$$

and

$$\Phi(K,L,F) = Q$$

$$K,L,F \geq 0 ,$$

the Lagrangean expression is given by

$$Z = P_L L + P_F F + P_K K - \lambda[R - P_L L - P_F F - sK] - \theta[Q - (K,L,F)] . \quad (A10)$$

The necessary conditions for cost minimization are:

$$\partial Z/\partial L = P_L + \lambda P_L + \theta \Phi_L = 0 \quad (A11)$$

$$\partial Z/\partial F = P_F + \lambda P_F + \theta \Phi_F = 0 \quad (A12)$$

$$\partial Z/\partial K = P_K + \lambda s + \theta \Phi_K = 0 \quad (A13)$$

$$\partial Z/\partial \lambda = - (R - P_L L - P_F F - sK) = 0 \quad (A14)$$

$$\partial Z/\partial \theta = (Q - \Phi(K,L,F)) = 0 \qquad \text{(A15)}$$

$$K, L, F, \theta, \lambda \geq 0 \; . \qquad \text{(A16)}$$

Solution of (A11)-(A16) yields the optimal (cost minimizing) choice variables:

$$K' = g_1(P_F, P_L, P_K, Q, s) \qquad \text{(A17)}$$

$$L' = g_2(P_F, P_L, P_K, Q, s) \qquad \text{(A18)}$$

$$F' = g_3(P_F, P_L, P_K, Q, s) \qquad \text{(A19)}$$

$$\lambda' = g_4(P_F, P_L, P_K, Q, s) \qquad \text{(A20)}$$

$$\theta' = g_5(P_F, P_L, P_K, Q, s) \; . \qquad \text{(A21)}$$

The revision of Shephard's Lemma proceeds as follows: differentiating (A10) with respect to P_L and collecting terms yields:

$$\begin{aligned} \partial Z/\partial P_L = {} & L(1 + \lambda) + \partial L/\partial P_L \; (P_L + \lambda P_L + \theta \Phi_L) \\ & + \partial F/\partial P_L \; (P_F + \lambda P_F + \theta \Phi_F) \\ & + \partial K/\partial P_L \; (P_K + \lambda s + \theta \Phi_K) \\ & + \partial \lambda/\partial P_L \; (-R + P_L L + P_F F + sK) \\ & + \partial \theta/\partial P_L \; (-Q + \Phi(K,F,L)) \; . \end{aligned} \qquad \text{(A22)}$$

Note that if the optimum values of the choice variables (obtained in (A17)-(A21)) are inserted in (A22), the necessary conditions for cost

minimization, (A11)-(A16), guarantee that all terms on the right hand side except for the first term become zero. Thus at the optimum solution we have

$$\partial Z/\partial P_L = \partial C'/\partial P_L = L'(1 + \lambda') \ , \tag{A23}$$

where primed notation denotes optimum values.

Similarly, differentiating (A10) with respect to P_F yields:

$$\begin{aligned}\partial Z/\partial P_F = F(1 + \lambda) &+ \partial L/\partial P_F \ (P_L + \lambda P_L + \theta \Phi_L) \\ &+ \partial F/\partial P_F \ (P_F + \lambda P_F + \theta \Phi_F) \\ &+ \partial K/\partial P_F \ (P_K + \lambda s + \theta \Phi_K) \\ &+ \partial \lambda/\partial P_F \ (-R + P_L L + P_F F + sK) \\ &+ \partial \theta/\partial P_F \ (-Q + \Phi(K,L,F)) \ .\end{aligned} \tag{A24}$$

When optimal choice variables are inserted, (A24) becomes

$$\partial Z/\partial P_F = \partial C'/ \ P_F = F'(1 + \lambda') \ . \tag{A25}$$

Similarly, differentiating (A10) with respect to P_K yields:

$$\begin{aligned}\partial Z/\partial P_K = K &+ \partial L/\partial P_K \ (P_L + \lambda P_L + \theta \Phi_L) \\ &+ \partial F/\partial P_K \ (P_F + \lambda P_F + \theta \Phi_F) \\ &+ \partial K/\partial P_K \ (P_K + \lambda s + \theta \Phi_K)\end{aligned}$$

$$+ \partial\lambda/\partial P_K \, (-R + P_L L + P_F F + sK)$$

$$+ \partial\theta/\partial P_K \, (-Q + \Phi(K,F,L)) \; . \qquad \text{(A26)}$$

When optimal choice variables are inserted, (A26) becomes

$$\partial Z/\partial P_K = \partial C'/\partial P_K = K' \; .$$

Finally, differentiating (A10) with respect to s,

$$\partial Z/\partial s = \lambda K + \partial L/\partial s \, (P_L + \lambda P_L + \theta \Phi_L)$$

$$+ \partial F/\partial s \, (P_F + \lambda P_F + \theta \Phi_F)$$

$$+ \partial K/\partial s \, (P_K + \lambda s + \theta \Phi_K)$$

$$+ \partial\lambda/\partial s \, (-R + P_L L + P_F F + sK)$$

$$+ \partial\theta/\partial s \, (-Q + \Phi(K,L,F)) \; . \qquad \text{(A28)}$$

When optimum values of the choice variables are inserted, (A28) becomes

$$\partial Z/\partial s = \partial C'/\partial s = \lambda' K' \; . \qquad \text{(A29)}$$

Summarizing the main results of this section, we have a "modified" Shephard's Lemma for the case of the regulated firm:

$$\partial C'/\partial P_L = L'(1 + \lambda') \qquad \text{(A23)}$$

$$\partial C'/\partial P_F = F'(1 + \lambda') \qquad \text{(A25)}$$

$$\partial C'/\partial P_K = K' \tag{A27}$$

$$\partial C'/\partial s = \lambda' K' \ . \tag{A29}$$

Since λ is not observable it must be eliminated from the equations. Adding (A27) and (A29) we have

$$(\partial C'/\partial P_K) + (\partial C'/\partial s) = (1 + \lambda')K' \tag{A30}$$

or

$$[(\partial C'/\partial P_K) + (\partial C'/\partial s)]/[\partial C /\partial P_K] = (1 + \lambda') \ . \tag{A31}$$

Substituting (A31) into (A25) and (A23) yields

$$L' = [(\partial C'/\partial P_K)(\partial C'/\partial P_L)]/[(\partial C'/\partial P_K) + (\partial C'/\partial s)] \tag{A32}$$

and

$$F' = [(\partial C'/\partial P_F)(\partial C'/\partial P_K)]/[(\partial C'/\partial P_K) + (\partial C'/\partial s)] \ . \tag{A33}$$

These results, together with (A27), constitute a revision of Shephard's Lemma for the case in which the firm is subject to rate of return regulation.

APPENDIX E

NONNEGATIVE RESTRICTIONS AND THE PROPERTIES OF THE GENERALIZED LEONTIEF COST FUNCTION

Under the restriction that its parameters are nonnegative the Generalized cost function satisfies conditions (49) of Chapter IV. When some parameters are negative these conditions may not be satisfied for some observations in the sample. Diewert (1971) has shown that in such a case the condition

$$\sum_j a_{ij} p_j^{1/2} \geq 0, \quad i = 1, \ldots, n \tag{A34}$$

is sufficient to guarantee that the cost function is nonnegative and nondecreasing in factor prices, while the condition

$$\sum_{j=2}^{n} a_{ij} p_j^{1/2} p_1^{-3/2} > 0$$

$$(\sum a_{ij} p_j^{1/2} p_1)(\sum a_{2j} p_j^{1/2} p_2) - a_{12}^2 p_1^{-1} p_2^{-1} \geq 0 , \tag{A35}$$

$$i = 1, \ldots, n$$

is sufficient to guarantee that the cost function is concave in factor prices, where n is the number of factors. Computation of (A34) and (A35) for the sample data using the estimated coefficients in Table 8, Chapter IV, page 73, reveals that the conditions are violated only for a very small number of sample observations.

VITA

Michael Z. Zimmer was born in Evansville, Indiana, on June 25, 1950. He attended primary and secondary schools in Evansville. He graduated from The University of North Carolina at Asheville in 1972, receiving a Bachelor of Arts degree in Mathematics and Economics. He entered The University of Tennessee in September 1972. He received the Master of Business Administration degree in December 1973, and the Doctor of Philosophy degree with a major in Economics in March 1977.

He is currently Assistant Professor of Economics at The University of Evansville in Evansville, Indiana. He is married to the former Martha Ellen Hill of Gadsden, Alabama.