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Multiple-Output Production and Pricing in Electric Utilities*

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I. Introduction

Empirical studies of the electric utility industry have generally focused on one of several issues, such as the presence or absence of regulation-induced input mix distortions, the rules used to select regulated prices, whether electricity is one output or several, or the "naturalness" of the electric utility monopoly.[1] This paper contributes a method which permits simultaneous estimation of demand elasticities, pricing rule parameters, and marginal rates of transformation within one econometric model. Since firms make input and output decisions given the demand and regulatory conditions facing them, the marginal rates of substitution and transformation are dependent on the demand elasticities of each consumer class and the prices permitted by regulators. Its purposes are two.

First, I examine the appropriateness of a multiple-output model of production: is electricity one output, or are the products sold to different consumers distinct outputs? Most, but not all, previous studies treat "electricity" as a homogeneous product.[2] While this assumption may be justified for studies which deal strictly with *generation* of electricity, Joskow and Schmalensee [27, 54–5] observe[3] that

> ... treating diverse power systems as single-product firms operating under identical conditions is likely to produce error. The cost of an optimally designed power system depends in complex ways on the distribution of demand over time and space. No two power systems produce the same mix of products, and product mix differences affect the magnitude and form of optimal investments in transmission and distribution.

I find strong evidence that the multiple-product characterization of electricity production is appropriate. I also find that the marginal cost of any one output depends on the levels of all

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[1] In a survey of early applied research, Cowing and Smith [10] mention 14 papers using four different methods of analysis to investigate one or more of these issues. Joskow and Schmalensee [27] discuss some more recent efforts.

[2] Multiple-output production has been analyzed for a number of industries, including railroads, by Brown, Caves and Christensen [7]; telecommunications, by Evans and Heckman [14]; automobile production, by Friedlaender, Wang and Winston [16]; and electric power, by Primeaux and Nelson [38], Eckel [13], Nelson, Roberts and Tromp [33], and Hayashi, Sevier and Trapani [23].

[3] This quote is motivated by an observation in [10]. Joskow and Schmalensee also remark on the multiple-output nature of electric power production [27, 34].

other outputs and all other inputs. In prior studies, less inclusive empirical models have simplified or eliminated these interrelationships. Such simplifications are a source of specification bias; policy implications drawn from such models may therefore be incorrect.

The model of producer behavior is more general than that used in other studies of multiple-output production of electricity. Hayashi, Sevier and Trapani [23] impose separability of inputs and outputs. Eckel [13] aggregates residential and commercial electricity into one output. The wholesale electricity market is omitted in both aforementioned papers and in Nelson, Roberts and Tromp [33]. In my research, residential and commercial electricity are distinct outputs. I model the participation of utilities in wholesale markets.

Second, I assess the rules underlying regulated electricity prices, recognizing the multiple-output character of electric power production. Once the different marginal costs and demand elasticities of the different products are incorporated in the analysis, the prices chosen by the sample firms are *indistinguishable* from those which would be chosen by profit-maximizing price-discriminating monopolists. While this result has been anticipated by Stigler and Friedland [40], Posner [36; 37], and Hilton [25], it has rarely appeared in empirical studies, principally because the methods in those studies were overly simplified.

My method has fewer data requirements and parameters than those followed by Meyer and Leland [30], Nelson [34] or Hayashi, Sevier and Trapani [23]. Meyer and Leland estimate demand equations with standard least-squares techniques, while they construct surrogate marginal cost measures as different multiples of the price of fuel. Nelson employs marginal cost estimates derived from Primeaux and Nelson [38] and demand elasticities from Mount, Chapman and Tyrrell [32]. Thus, these studies do not capture the simultaneity of firm decision making. Hayashi, Sevier and Trapani [23] estimate both consumer demand equations (using standard linear regression) and marginal costs (using a translog cost function) as separate models, although they use data from the same set of firms in all regressions. In addition to characterizing a simultaneous process with separate models, they must gather data for both a translog cost function model and a model of consumer demand.

By contrast, I estimate the demand elasticities and marginal rates of transformation as part of a single model of production. The elasticities are identified as parameters within a system of behavioral equations, which permits a simpler model: it is not necessary to obtain income, substitute price, or demographic data, as required by the standard demand equation approach.[4] Similarly, the rules used by regulators to select prices are identified as part of the system of equations.[5]

II. Producer Behavior

Production Theory

Production in the electric power industry is a multiple-output process: although kilowatt-hours delivered to industrial, residential, commercial and wholesale customers are produced in large part with common facilities, they may be distinct products with different marginal costs and demand elasticities.

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[4] Nelson, Roberts and Tromp [33] present a similar model, but based on a cost function rather than a production function.

[5] The model in this paper is specified for regulated electric utilities. The basic specification, without the regulatory variables, can be applied to any multiproduct firm.

The industry's production process is thus represented by a transformation function involving four outputs (Q) and four inputs (X):

$$Q_I = G(Q_R, Q_C, Q_W, X_L, X_K, X_F, X_Z), \tag{1}$$

where G is a well-behaved transformation function.[6] The subscripts on Q denote the industrial (I), residential (R), commercial (C) and wholesale (W) customer classes, respectively; the subscripts on X denote the utilities' major inputs, labor (L), fuel (F), capital (K) and purchased power (Z).

Producers purchase their inputs in competitive factor markets and sell kilowatt-hours to a competitive wholesale market and in imperfectly competitive industrial, residential and commercial markets.[7] Each utility is a price taker in the wholesale market and in all input markets; in its remaining product markets, it faces a downward sloping demand curve,

$$P_m = h^m(Q_m,\mathbf{Y}), \quad \text{with } \partial h^m / \partial Q_m < 0, \quad m = I,R,C \tag{2}$$

where P_m is the price of Q_m, h^m is the aggregate demand for product m and $\mathbf{Y}$ is a vector of variables including consumers' income and the prices of other goods.[8] The price elasticity of demand for output m is η_m.

In this model, production for each consumer class equals consumption by that class. The industry's inability to store electricity implies producers plan for zero inventories.

A purely profit-maximizing firm would maximize profits,

$$\pi = \sum_{m=R}^{C,I} h^m(Q_m,\mathbf{Y}) Q_m + P_W Q_W - \sum_{j=L,K}^{F,Z} p_j X_j \tag{3}$$

subject to the transformation frontier (1). The solution to this problem is characterized by the following first-order conditions.[9]

$$\partial G/\partial Q_m = -[P_m(1-(1/\eta_m))]/[P_I(1-(1/\eta_I))], \quad m = R, C, W; \tag{4a}$$

$$\partial G/\partial X_j = p_j/[P_I(1-(1/\eta_I))], \quad j = L,K,F,Z. \tag{4b}$$

Equations (4) are standard: a profit-maximizing firm will choose the output mix at which the marginal rate of transformation between two outputs equals the relative marginal revenues, and each input such that its marginal revenue product equals its price.

Regulatory Policy

Equations (4) characterize the input and output choices of an unregulated profit-maximizing firm. Utilities, however, are regulated: the problem of characterizing this regulation is addressed here.

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[6] Diewert [11] presents a discussion of the properties of transformation functions.

[7] Joskow and Schmalensee [27, 36–7] show that interconnected electric utilities operate most efficiently when the loss-adjusted marginal cost of each operating generating plant is the same. The low cost of transmitting electricity over long distances and the national network of interconnecting transmission facilities give a competitive character to the wholesale market.

[8] Existing studies of the demand for electricity generally require the researcher to control for the shift variables $\mathbf{Y}$. The model presented in this paper makes estimation of the demand elasticities possible without attempting to obtain actual or proxy measures of $\mathbf{Y}$. Taylor [41] surveys a number of studies and discusses elements of $\mathbf{Y}$ used there; some rather complicated specifications also appear in Meyer and Leland [30] and Hayashi, Sevier and Trapani [23].

[9] This derivation follows from Henderson and Quandt [24, 95–100] generalized to incorporate price-making behavior. Expressions (4) are Kuhn-Tucker conditions which may hold as inequalities if any Q_m or X_j are zero.

"Regulation" of the electric utilities is frequently modeled as a "rate of return" constraint imposed on the profit maximizing firm. This form of regulation leads to the "Averch-Johnson effect" [2]: an over-intensive use of capital relative to the cost-minimizing input mix for the same output mix. The Averch-Johnson view of regulation has been criticized elsewhere. The most damaging criticism of the Averch-Johnson model is that it is too static. A firm's input mix at any time actually depends on past realizations and future expectations of regulatory policy.[10] The Averch-Johnson distortion arises if investments are perfectly reversible or if a regulated firm makes a positive investment in every period of its life *and* the firm never incurs a loss.

In an alternative view of regulation, the regulators are concerned primarily with price *levels* and *relative* prices, and secondarily with rates of return.[11] The "rate of return constraint" is satisfied through the choice of prices by regulators. This type of regulation implies the use of "inverse elasticity" or "Ramsey optimal" pricing as formalized by Baumol and Bradford [5]. Under the inverse elasticity rule,[12]

$$P_m[1-((\lambda-1)/\lambda)(1/\eta_m)] = MC_m, \quad m = R,C,I,W \tag{5}$$

where λ is the Lagrange multiplier associated with the minimum profit constraint the regulator must satisfy. The "Ramsey number" associated with this form of regulation is $(\lambda-1)/\lambda$. Since the profit constraint is empirically unknown, there are no data on the Ramsey number: the multiplier λ cannot be identified as an estimable parameter.

Ross [39, 152] modifies inverse-elasticity pricing: "regulators choose prices to maximize *some* weighted sum of consumers' and producer's surpluses". He presents a technique for obtaining the regulators' weights given data on price, marginal costs, and demand elasticities. One approach that Ross uses is to weight the implied social welfare function by the share of each consumer class in the consumption of a good.[13] If the regulators are weighting deviations of prices from marginal costs by the share of consumer class m in total output, S_m, the relationship of price and marginal cost is given by

$$P_m[1-((\lambda-\zeta_m S_m)/\lambda)(1/\eta_m)] = MC_m, \quad m = I,R,C,W \tag{6}$$

where ζ_m is the social welfare weight the regulators attach to consumption of consumer class m. Expressions (4) become

$$\partial G/\partial Q_m = -[P_m(1-(1-\kappa_m S_m)(1/\eta_m))]/[P_I(1-(1-\kappa_I S_I)(1/\eta_I))] \quad m = R,C,W \tag{7a}$$

$$\partial G/\partial X_j = p_j/[P_I(1-(1-\kappa_I S_I)(1/\eta_I))], \quad j = L,K,F,Z \tag{7b}$$

where $\kappa_m = \zeta_m/\lambda$. While neither the Lagrange multiplier λ nor the social welfare weight ζ_m

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[10] Gollop and Karlson [19] present an intertemporal model of investment in the electric power industry in order to overcome the problem. Their paper is a first attempt which does not incorporate the costs of adjusting investment to a desired level each year.

[11] Joskow [26, 298]: "Contrary to the popular view, it *does not* appear that regulatory agencies have been concerned with raising rates of return per se. The primary concern of regulatory commissions has been to keep *nominal prices from increasing.*" (The emphasis is in the original work.)

[12] There are a number of different specifications for this rule. Expression (5) and subsequent discussion follow Ross [39].

[13] The share weighting approach is similar to a weighting approach used by Feldstein [15] to solve an optimal taxation problem. Nelson [34] proposes that consumers whose share of electricity consumption is large receive price concessions from regulators.

can be identified in the estimating model, their ratio is identifiable. The weight regulators attach to deviations from marginal cost pricing is thus given for each consumer class by $1 - \kappa_m S_m$.

Another possible regulatory policy is marginal cost pricing. In this event, we would observe marginal rates of transformation equal to relative product prices, while the value of the marginal product of each input would equal its price.

Econometric Model

An econometric model must be derived from the multiple-output optimization problem.[14] First, the production correspondence (1) is approximated with the translog transformation function[15]

$$\begin{aligned}\ln Q_I = \alpha_0 &+ \sum_{m=R}^{C,W} \alpha_m \ln Q_m + \sum_{j=L,K}^{F,Z} \alpha_j \ln X_j + 0.5 \sum_{m} \sum_{n=R}^{C,W} \beta_{mn} \ln Q_m \ln Q_n \\ &+ 0.5 \sum_{j} \sum_{k=L,K}^{F,Z} \gamma_{jk} \ln X_j \ln X_k + \sum_{m} \sum_{j} \phi_{mj} \ln Q_m \ln X_j. \qquad (8)\end{aligned}$$

The logarithmic marginal rates of transformation and logarithmic marginal products are

$$\partial \ln Q_I / \partial \ln Q_m = \alpha_m + \sum_{n=R}^{C,W} \beta_{mn} \ln Q_n + \sum_{j=L,K}^{F,Z} \phi_{mj} \ln X_j, \quad m = R,C,W; \qquad (9a)$$

$$\partial \ln Q_I / \partial \ln X_j = \alpha_j + \sum_{m=R}^{C,W} \phi_{mj} \ln Q_m + \sum_{k=L,K}^{F,Z} \gamma_{jk} \ln X_k, \quad j = L,K,F,Z. \qquad (9b)$$

The most general regulatory condition is (7). It transforms conditions (9) to give

$$\begin{aligned}P_m Q_m / P_I Q_I = &- [(1-(1-\kappa_I S_I)(1/\eta_I)) \;/\; (1-(1-\kappa_m S_m)(1/\eta_m))] \\ &\times [\alpha_m + \sum_{n=R}^{C,W} \beta_{mn} \ln Q_n + \sum_{j=L,K}^{F,Z} \phi_{mj} \ln X_j] \qquad (10a)\end{aligned}$$

$$p_j X_j / P_I Q_I = (1-(1-\kappa_I S_I)(1/\eta_I)) [\alpha_j + \sum_{m=R}^{C,W} \phi_{mj} \ln Q_m + \sum_{k=L,K}^{F,Z} \gamma_{jk} \ln X_k]. \qquad (10b)$$

The estimating equations are obtained by adding disturbances to the behavioral equations (10) and the transformation frontier (8). The resulting eight equations are estimated as a multivariate regression system. To avoid simultaneity bias caused by the endogeneity of all outputs and inputs, estimation employs the method of iterative nonlinear three stage least squares.[16] Price and quantity data for the inputs and outputs are observed directly; the

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[14] The derivation here parallels the development of a single-output model presented in Gollop and Karlson [19]. More detailed expositions of the modeling techniques employed in this research are presented in two unpublished working papers, Gollop and Karlson [20; 21].

[15] The translog transformation function was introduced by Christensen, Jorgensen and Lau [9]. In order to reduce the number of parameters, industrial power is arbitrarily chosen as the "dependent variable" in (8). Different orderings of the outputs could result in different translog descriptions of the underlying technology. Diewert [12, 129] suggests that the resulting descriptions ". . . should be close in empirical applications since the different translog functions are all approximating the same technology to the second order."

[16] The eight instruments are a unitary constant, the prices of labor, capital and fuel inputs, and the numbers of residential, commercial, industrial and wholesale customers.

demand elasticities, technology coefficients and regulatory effect variables are estimable parameters.

Hypotheses

There are two groups of hypotheses which will be tested in this research. The first is a test of the appropriateness of the multiple-output specification of the structure of production. A sufficient test for multiple-output production is the rejection of the hypothesis of separability[17] of inputs and outputs, which would allow (1) to be rewritten as

$$Q_I = G(f(Q_R, Q_C, Q_W), g(X_L, X_K, X_F, X_Z)). \tag{11}$$

The separability hypothesis involves 12 restrictions,

$$H_o\colon \phi_{mj} = 0, \text{ all } m, \text{ all } j. \tag{12}$$

Separability of inputs from outputs implies that the marginal rate of substitution between any two inputs is independent of the quantities of outputs, *and* the marginal rate of transformation between any two outputs is independent of the quantities of inputs. Rejection of the null hypothesis of separability *implies* that the relative marginal costs of electricity sold to different consumer classes depend on the product and input mixes; furthermore, it is impossible to construct some homogeneous aggregate output called "electricity" to be sold to all customers.[18] A multiple-output model of production is thus appropriate.

The second group of hypotheses deals with the effect of regulation on pricing. The model specifies that regulators choose prices such that consumers do not face pure monopoly prices, but rather prices which deviate from pure monopoly prices in a way weighted by shares of consumption. Two null hypotheses are tested against this maintained hypothesis. The first hypothesis is "monopoly pricing":

$$H_o\colon \kappa_I = \kappa_R = \kappa_C = 0. \tag{13}$$

Under this null hypothesis, the prices *permitted* by the regulators *are* those chosen by a profit maximizing monopolist. The second hypothesis is "marginal cost pricing":

$$\begin{gathered} H_o\colon \kappa_I = \kappa_R = \kappa_C = 0 \text{ and} \\ 1/\eta_I = 1/\eta_R = 1/\eta_C = 0. \end{gathered} \tag{14}$$

Under this null hypothesis, the regulators require the price of each kind of electricity to equal its marginal cost.[19]

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[17] The model imposes some separability in that an implicit transformation frontier is solved for one output. Such a solution can be postulated whenever the transformation frontier is well-behaved; the solution does not sacrifice any marginal rates of substitution or transformation, but it reduces the number of free parameters in the model.

[18] Although separability of inputs and outputs implies aggregation of output is possible, it does *not* imply that the marginal costs of all types of electricity are the same. Another step is required: is the marginal rate of transformation between any two outputs in the aggregate always unity? If so, a single-output production function could be used to model the production of electricity. If the marginal rate of transformation depends on input levels, it cannot be unity everywhere: rejection of separability is *sufficient* evidence of multiple-output production.

[19] If regulators impose marginal cost pricing on utilities, it does not follow that consumer demands for electricity are infinitely elastic. Rather, the utility must provide whatever electricity consumers demand at those prices; it will do so most efficiently if it selects inputs and outputs on the basis of those relative product and input prices.

III. Estimation and Test Results

Data

The econometric model is estimated on a sample of 28 privately-owned electric utilities which rely primarily on coal-fired generation. The sample is restricted to firms which have adopted a similar technology and exist in substantially similar market and regulatory environments.[20] Engineering considerations and econometric research strongly suggest that generation technologies differ among fuel types.[21] Coal-fired utilities have accounted for an increasing share of U.S. electricity production; in 1978, 44 percent of U.S. electricity was so produced [42, ii].

Firms which are either publicly owned or earn more than one-third of their revenue from the distribution of natural gas[22] are excluded from the data set. Publicly owned utilities face different regulatory constraints; their managements may have different objectives from those of investor-owned utilities. Combination utilities are likely to share managers, billing services, maintenance and some physical plant between their electric and gas divisions.

Utilities which purchase no power from wholesale markets or which fail to supply power to all four consumer classes are excluded from the data set. For such firms, conditions (4) may hold as inequalities, implying behavioral conditions (10) do not hold.

The technological, institutional and mathematical selection criteria lead to a sample of 28 utilities from an initial population of over 170 publicly and privately-owned firms. The econometric model, equations (8) and (10), is used to analyze the behavior of these firms in 1978.

The model is constructed under the assumption that firms are in long-run equilibrium. Data is gathered for the 28 firms for 1978. This calendar year predates the second oil shock of 1979 and the decontrol of crude oil prices in 1981. It is also well after the first OPEC shock of 1973.

Most of the data required for the model are described in Gollop and Karlson [22]. Additional data are obtained directly from the *Statistics of Privately Owned Electric Utilities* [43].

Input price and input expenditure data are described in [22]. Labor and fuel expenditures are obtained from the Federal Energy Regulatory Commission. Capital input and capital expenditures are constructed using a data base prepared by Christensen, Gollop and Stevenson [8]. Purchased power expenditures are the imputed cost of purchased power and positive net interchanges: the measure of purchased power expenditures is thus different from that reported in [43] for those firms with negative net interchanges.[23]

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[20] There are over 180 degrees of freedom in this estimating system since there are eight equations used to estimate no more than 42 parameters.

[21] Boyes [6, 28] discusses the differences in utility technology due to fuel choice. Gollop and Karlson [18] reject the hypothesis of identical coefficients in electric utility cost functions among regions of the U. S., implying differences in the underlying technology. The sample evaluated in this study is restricted to northern coal-fired electric utilities in order to make the observations more homogeneous. Northern utilities must keep their boilers and condensers enclosed to protect against severe winters; southern utilities often place much of this equipment outside.

[22] Of the 28 firms, 16 are purely electric utilities; no combination utility obtains more than 33 percent of its 1978 revenues from gas sales.

[23] Interchanges are *exchanges* of power between generating companies, generally to reduce the cost of providing

Table I. Parameter Estimates

Parameter	Estimate	Parameter	Estimate
α_0	1.02^a	γ_{FF}	$-.548$
α_R	-1.05	γ_{FZ}	-5.3×10^{-3}
α_C	$-.202$	γ_{ZZ}	-5.1×10^{-5}
α_W	$-.567^b$	ϕ_{RL}	$-.215$
β_{RR}	-2.7×10^{-5}	ϕ_{RK}	$-.319$
β_{RC}	-6.1×10^{-4}	ϕ_{RF}	$.661$
β_{RW}	-4.4×10^{-3}	ϕ_{RZ}	$-.293$
β_{CC}	$-.014$	ϕ_{CL}	$-.152$
β_{CW}	$-.098$	ϕ_{CK}	$.181$
β_{WW}	$-.707$	ϕ_{CF}	$.146$
α_L	$.059$	ϕ_{CZ}	7.5×10^{-3}
α_K	1.54^a	ϕ_{WL}	$.260$
α_F	1.45^a	ϕ_{WK}	$.405$
α_Z	$.182$	ϕ_{WF}	$.443$
γ_{LL}	-1.9×10^{-4}	ϕ_{WZ}	$.160$
γ_{LK}	4.6×10^{-3}	η_I	2.14
γ_{LF}	$.010$	η_R	1.83
γ_{LZ}	9.8×10^{-5}	η_C	1.22^a
γ_{KK}	$-.113$	κ_I	-1.3×10^{-4}
γ_{KF}	$-.249$	κ_R	6.3×10^{-5}
γ_{KZ}	-2.4×10^{-3}	κ_C	-3.7×10^{-5}

a. Significant at the 95% level.
b. Significant at the 90% level.

Revenues for sales to residential, industrial and commercial customers, as well as quantities sold to these consumer classes, are reported in [43]. Physical sales for resale, and resale revenues, are not those reported in [43] for firms with negative net interchanges.[24] In this paper, power which is interchanged out to other utilities is treated as a sale for resale. Hence, "sales for resale" is defined as the sum of reported sales for resale and the absolute value of negative net interchanges. The imputed revenue from sales for resale is computed such that the difference between revenue from sales for resale and purchased power expenses used in the data set is equal to the difference between those entries reported in [43].

Since the translog transformation frontier is an approximation based on a Taylor expansion around zero, all input and output data are scaled to their means.

Estimates

The parameter estimates obtained by the multivariate regression system (expressions (8) and (10)) are reported in Table I. The estimates satisfy the efficiency conditions (symmetry,

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power, but sometimes to permit a generator to be taken out of service for maintenance. Interchanges differ from sales for resale, which arise when a utility with generating capacity *sells* power to another utility, generally a distribution utility with no generating capacity of its own. While [43] reports separate entries for *quantities* sold for resale or interchanged, one account, "purchased power expenses", contains both expenditures on purchased power (a positive number), and the *balance* resulting when utilities settle accounts for interchanges (which may be positive or negative for any firm).

[24] Six firms report negative purchased power expenses in [43]. The revenue and cost recalculations generate positive purchased power expenses (for purchases listed in [43]) and positive revenues from sales for resale (reflecting reported sales for resale and net interchanges out).

monotonicity and concavity) required by the theory of production. Symmetry is a maintained hypothesis, imposed by specifying $\beta_{mn} = \beta_{nm}$, $\gamma_{ij} = \gamma_{ji}$ and $\phi_{im} = \phi_{mi}$. The monotonicity conditions are satisfied: each input's marginal product is positive in the input level, since α_L, α_K, α_F and α_Z are all positive, while the marginal rate of transformation between kilowatt-hours produced for industrial use and electricity produced for each other customer class is negative, since α_R, α_C and α_W are all negative. The sufficiency conditions for concavity are satisfied given the estimates of the *own* second-order input parameters γ_{ii} and output coefficients β_{mm}.[25] Consequently, marginal products of inputs are positive and decreasing functions of input levels, while marginal rates of transformation are negative and decreasing functions of output levels.

Separability and Joint Production

Although no ϕ_{im} parameter is *individually* significant, the χ^2 statistic[26] associated with the test of the separability hypothesis (12) is 59.563, well above the 99% critical value of 26.217 with twelve degrees of freedom. Since inputs and outputs are not separable, the interdependencies among the inputs and the outputs *jointly* exert a significant influence on the transformation possibilities.

That the transformation function is not separable in inputs and outputs implies there are potential biases in some prior research. In Primeaux and Nelson [38], the marginal cost of electricity to each consumer class depends in part on the output mix at each firm's peak demand, but the input mix in generation is held invariant to output mix. In Meyer and Leland [30], marginal costs are markups of the fuel marginal cost; these are affected by neither the output mix nor the input mix. Hayashi, Sevier and Trapani report a model in which separability is maintained [23, 783]; they do not test this restriction.

Regulated Pricing

The parameters reported in Table I also permit some statements about the social welfare weights used by regulators in setting the prices of electricity faced by residential, commercial and industrial consumers. The null hypothesis (13) that $\kappa_I = \kappa_R = \kappa_C = 0$, i.e. that regulated prices are profit-maximizing prices cannot be rejected. The χ^2 statistic associated with the hypothesis test is 0.027, which is not statistically significant.

This test statistic is not an artifact of the very nonlinear estimation system which emerges when all parameters in equations (8) and (10) are estimated. As a check on this possibility, I treated the Mount-Chapman-Tyrrell [32] average elasticity estimates as constants,[27] estimating only the κ_m and the production parameters. In that model, the χ^2 statistic

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[25] These coefficients are obtained under a reparameterization of the basic translog model which permits a check for concavity. The reparameterization follows Lau [29]. The coefficients obtained in an unrestricted translog model did not satisfy the concavity conditions; I imposed restrictions on the reparameterized model until the sufficiency conditions for concavity were satisfied. The reparameterization permits the calculation of all the second-order parameters, which are reported in Table I.

[26] All χ^2 statistics are calculated according to a procedure derived in Gallant and Jorgenson [17]. The test statistic T is based on the increase in the weighted mean-squared error of the regression system when the parametric restrictions are imposed. Its formula is $T = N(\mathrm{trace}(W'C_rW) - \mathrm{trace}(W'C_fW))$ where N is the number of observations, W is the Choleski weighting matrix for the *unrestricted* model, C_r is the covariance matrix of untransformed residuals of the restricted model and C_f is the covariance matrix of untransformed residuals in the unrestricted model.

[27] Eckel [13] and Nelson, Roberts and Tromp [33] both use Mount-Chapman-Tyrrell [32] elasticities as constants.

associated with setting three κ_m to zero was 1.05, still not significant. The 95% critical value of the χ^2 distribution with three degrees of freedom is 7.81.

This result is surprising, since it is at odds with some published research and the institutional wisdom that regulators "do something" to protect consumers against "monopoly" rates. Does the absence of any regulatory effect on pricing imply that regulators have failed at their task?

First, prior research does not allow for the richness of substitution and transformation possibilities among inputs and outputs possible using the translog transformation frontier. Studies by Primeaux and Nelson [38], Meyer and Leland [30] and Hayashi, Sevier and Trapani [23] explicitly or implicitly assumed separability of inputs and outputs. Imposing separability leads to estimates of relative marginal costs which are incorrect. To show this, I estimated a model that imposed separability of inputs and outputs. In that model, the estimates of κ_I, κ_R and κ_C were, respectively, $-.205$, $-.090$ and $-.039$. When the null hypothesis of monopoly pricing was tested, a χ^2 statistic of 9.506 resulted: with 97.5 percent confidence, I would reject the null hypothesis that these prices were pure monopoly prices: furthermore, regulators would grant larger price concessions to industrial consumers than to residential or commercial customers with the same share of a utility's output. But those conclusions would be erroneous because the hypothesis of separability in production was rejected. Consequently, the *estimates* that regulation reduces electricity prices are due to *specification error* in the measurement of marginal cost.

The papers by Eckel [13] and Nelson, Roberts and Tromp [33] do not impose separability, but they also study different samples. Eckel's results are obtained from a 1970 sample of unreported size and composition. Nelson, Roberts and Tromp study 69 utilities in 1970 and 1978. They do not specify the composition of the data set, which raises the possibility that utilities using different fuels, or different construction techniques, are included in the sample. This raises the possibility that their finding of an effect of regulation on utility prices (in both years, but 1978 is relevant to this study) is the result of an attempt to fit one cost function to diverse technologies.

Second, the estimated long-run demand elasticities are larger than most prior estimates[28] for residential and industrial demands, but smaller for commercial customers.[29] Consequently, the implicit profit-maximizing price associated with *any* marginal cost would be lower for residential and industrial users, and higher for commercial consumers, if these elasticities were used in preference to Mount, Chapman and Tyrrell [32] elasticities. Both Meyer and Leland [30] and Nelson [34] observed changes in relative regulated prices in favor of residential consumers. They attribute this change to regulatory policy; the results here would be equally due to rational pricing by utilities.

Third, the hypothesis that regulation does not have an effect on pricing has been articulated previously. Stigler and Friedland [40] suggest that the ineffectiveness of regulation (of electric utility rates prior to 1937) can be due to one of two things: the monopoly power of the utility is slight; or the regulator is incapable of monitoring every decision of the firm. Posner [36, 34] contends "profit regulation may have little actual effect on monopoly prices

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[28] See Taylor [41] and Nelson [34] for discussions of previous values of demand elasticities.

[29] Although the estimated elasticities of demand have similar values and the point estimate for each elasticity lies within the 95 percent confidence interval for any other elasticity, a test of the null hypothesis that all three elasticities are equal to each other leads to a χ^2 statistic of 68.27, well above the 99% critical value of 9.21 for two degrees of freedom.

and profits". Moore [31] presents evidence that regulation has little effect on prices charged by privately owned utilities.[30] Hilton's [25, 50] "basic behavior of regulatory commissions" is to "generate monopoly gain . . . [by] maintaining a monopoly, and then to dissipate it by uneconomic activity".

Are any of these arguments valid for 28 regulated electric companies in 1978? Certainly regulators in 1978 face the same monitoring difficulties as their 1930s counterparts. But does the evidence show "slight" monopoly power or "uneconomic dissipation"? Stigler and Friedland's dismissal of "monopoly power" for utilities is based on a very high long-run elasticity of demand for electricity (they use 8; the highest value reported in Taylor [41] is 2; the values in this paper are 2.14 or less). Alberts [1, 626] has shown that *single-product* firms facing demand elasticities in the unitary to 2 range are capable of earning above 100 percent rates of return. No utility in 1978 did that well.

Consider, however that *wholesale* power is priced at its marginal cost. Furthermore, these *multiproduct* electric utilities operate under conditions of decreasing ray average cost.[31] Baumol [3] demonstrates complete marginal cost pricing cannot cover all the costs of a firm operating under those cost conditions. The marginal cost pricing hypothesis is convincingly rejected: the χ^2 statistic for this test is 999.90; the 99% critical value with six degrees of freedom is 16.81. Given decreasing ray average cost, and given that wholesale power is priced at marginal cost, prices which cover the costs of the multiple product electric utility could be indistinguishable from prices chosen according to the monopoly price-discrimination rule.[32]

Furthermore, some previous published research finds evidence of utility behavior not inconsistent with the profit-maximizing hypothesis. Implicitly, the Averch-Johnson model of regulation carries with it the hypothesis of monopoly profit-maximizing behavior. Boyes [6, 28] observes that absent an Averch-Johnson effect, "the model collapses to the traditional non-regulated profit-maximizing model." Since neither Boyes nor Gollop and Karlson [19] found evidence of an Averch-Johnson input mix distortion, both provide evidence of profit-maximizing behavior by regulated firms.

IV. Conclusions

The multiple output model of production and consumption yields a number of implications. First, the multiple output specification is appropriate: electric utilities produce distinct products for markets with distinct demand characteristics. The research shows that different consumer classes have different elasticities of demand for electricity. The prices which consumers face are not different from those which would be chosen by a profit-maximizing monopolist. Given the evidence of decreasing ray average costs in this sample, however, such discriminatory prices may be necessary to cover the costs of the firms. Marginal cost

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[30] Moore [31] presents a simple model in which a firm sells electricity only to residential customers. Its marginal cost is estimated by a linear regression. Moore's simplifications sacrifice many of the substitution and transformation possibilities analyzed here.

[31] These results are discussed in the working paper version of this research, which is available from me on request.

[32] Chapter 5 of volume I of Kahn [28] covers the role of price discrimination in covering the costs of natural monopolies.

pricing can not be sustained without subsidy under decreasing ray average costs. The null hypothesis of marginal cost pricing for all outputs was in fact rejected.

Each consumer class buys a unique product, each output has a different marginal cost; each marginal cost depends on the mix of inputs and outputs in each firm. Hence researchers seeking evidence of price discrimination, cross-subsidization, or Ramsey pricing in electricity rates may create specification bias in their models by imposing separability. The regulatory policy implications drawn from the unrestricted model of production are very different from those obtained when separability is imposed.

The research also illustrates the sensitivity of findings to the specification of models and the choice of data sets.

Does the presence of natural monopoly in electricity production suggest that deregulation cannot be applied to electric utilities to the extent it has been applied in transportation? Joskow and Schmalensee [27] endorse this position: of four possible deregulatory scenarios they consider, three envision continued regulation of at least the distribution and transmission networks, which are viewed as the source of the natural monopoly.

Their fourth scenario is complete deregulation of electric utilities. They rule out this policy [27, 154], arguing that deregulated firms would, in the short run, raise their prices further and engage in price discrimination to maximize their profits. The evidence in this paper suggests that these 28 *regulated* utilities were doing exactly that in 1978. Under complete deregulation, these consumers would be no worse off. There is in fact a *possibility* that consumer welfare could be improved under deregulation. All prices[33] are at least as high as marginal costs in this sample. Production is at least cost, and ray average costs are declining. These conditions are among those necessary for the "sustainability" of a natural monopoly against entry. If the necessary conditions[34] are satisfied, a deregulated natural monopoly can choose a set of output prices which will deter entry. Baumol, Bailey and Willig [4] show that, if there are prices sustainable against entry, those sustainable prices include Ramsey-optimal prices, i.e., prices that maximize social welfare yet cover all the costs of the regulated firm. Under deregulation, we would expect incumbent utilities to charge entry-deterring prices. If current regulated prices are higher than such prices, complete deregulation of electricity production could make consumers better off.

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[33] This model uses average prices of electricity; a generalization would control for the "block" structure of electricity prices. Primeaux and Nelson [38] find "internal subsidization" in block pricing structures: the price of the last block of electricity is less than its marginal cost. They do not compute the stand-alone costs of power to each consumer group.

[34] The necessary conditions are presented in Panzar and Willig [35].

References

1. Alberts, William W., "Do Oligopolists Earn 'Noncompetitive' Rates of Return?" *American Economic Review*, September 1984, 624–32.

2. Averch, Harvey and Leland H. Johnson, "Behavior of the Firm under Regulatory Constraint." *American Economic Review*, December 1962, 1053–69.

3. Baumol, William J., "On the Proper Cost Test for Natural Monopoly in a Multiproduct Industry." *American Economic Review*, December 1977, 809–22.

4. ———, Elizabeth E. Bailey, and Robert D. Willig. "Weak Invisible Hand Theorems on the Sustainability of Prices in a Multiproduct Monopoly." *American Economic Review*, June 1977, 350–65.

5. ——— and David E. Bradford, "Optimal Departures from Marginal Cost Pricing." *American Economic Review*, June 1970, 265–83.

6. Boyes, William J., "An Empirical Examination of the Averch-Johnson Effect." *Economic Inquiry*, March 1976, 25–35.

7. Brown, Randall S., Douglas W. Caves, and Laurits R. Christensen, "Modelling the Structure of Cost and Production for Multiproduct Firms." *Southern Economic Journal*, July 1979, 256–73.

8. Christensen, Laurits R., Frank M. Gollop, and Rodney E. Stevenson. "Measuring Capital Input in the Electric Power Industry," unpublished manuscript, University of Wisconsin-Madison, 1980.

9. ———, Dale W. Jorgenson, and Lawrence J. Lau, "Transcendental Logarithmic Production Frontiers." *Review of Economics and Statistics*, February 1973, 28–45.

10. Cowing, Thomas G., and V. Kerry Smith, "The Estimation of Production Technology: A Survey of Econometric Analyses of Steam-Electric Generation." *Land Economics*, May 1978, 155–86.

11. Diewert, W. Erwin, "Functional Forms for Profit and Transformation Functions." *Journal of Economic Theory*, June 1973, 284–316.

12. ———, "Exact and Superlative Index Numbers." *Journal of Econometrics*, May 1976, 115–45.

13. Eckel, Catherine C. "Are Customer Class Price Differences Justified? Electric Utility Price Discrimination in the U. S.," unpublished working paper, Virginia Polytechnic Institute, November 1984.

14. Evans, David S. and James J. Heckman, "A Test for Subadditivity of the Cost Function with an Application to the Bell System." *American Economic Review*, September 1984, 615–23.

15. Feldstein, Martin S., "Distributional Equity and the Structure of Public Prices." *American Economic Review*, March 1972, 32–36.

16. Friedlaender, Ann F., Clifford Winston, and Kung Wang, "Costs, Technology and Productivity in the U. S. Automobile Industry." *Bell Journal of Economics*, Spring 1983, 1–20.

17. Gallant, A. Ronald and Dale W. Jorgenson, "Statistical Inference for a System of Simultaneous, Non-Linear Implicit Equations in the Context of Instrumental Variable Estimation." *Journal of Econometrics*, October/December 1979, 275–302.

18. Gollop, Frank M. and Stephen H. Karlson, "The Impact of the Fuel Adjustment Mechanism on Economic Efficiency." *Review of Economics and Statistics*, November 1978, 574–84.

19. ——— and ———, "The Electric Power Industry: An Econometric Model of Intertemporal Behavior." *Land Economics*, August 1980, 299–314.

20. ——— and ———, "Demand Elasticities and Transformation Possibilities in the Electric Power Industry: A Multiple-Output Model of Production." Wayne Economic Paper 85, 1980.

21. ——— and ———. "Returns to Scale in Multiproduct Firms: An Application to the Electric Power Industry," Wayne Economic Paper 89, 1980.

22. ——— and ———, "Supplement on Statistical Analysis of Efficiency Effects," Appendix A in "Automatic Adjustment Clauses in Public Utility Rate Schedules." U. S. Department of Energy, Federal Energy Regulatory Commission, 1982, 73–158.

23. Hayashi, Paul M., Melanie Sevier, and John M. Trapani, "Pricing Efficiency Under Rate-of-Return Regulation: Some Empirical Evidence for the Electric Utility Industry." *Southern Economic Journal*, January 1985, 776–92.

24. Henderson, James M. and Richard E. Quandt. *Microeconomic Theory: A Mathematical Approach*, 2nd ed. New York: McGraw-Hill, 1972.

25. Hilton, George W., "The Basic Behavior of Regulatory Commissions." *American Economic Review*, May 1972, 47–54.

26. Joskow, Paul, "Inflation and Environmental Concern: Structural Change in the Process of Public Utility Regulation." *Journal of Law and Economics*, October 1974, 291–328.

27. ——— and Schmalensee, Richard. *Markets for Power: An Analysis of Electrical Utility Deregulation*. Cambridge, Mass.: The MIT Press, 1983.

28. Kahn, Alfred E. *The Economics of Regulation: Principles and Institutions*, Vol. I. New York: John Wiley and Sons, 1970.

29. Lau, Lawrence J. "Testing and Imposing Monotonicity, Convexity and Quasi-Convexity Constraints," in *Production Economics: A Dual Approach to Theory and Applications*, edited by Melvin Fuss and Daniel McFadden. Amsterdam: North-Holland Publishing Co., 1978, pp. 409–23.

30. Meyer, Robert A. and Hayne E. Leland, "The Effectiveness of Price Regulation." *Review of Economics and Statistics*, November 1980, 555–66.

31. Moore, Thomas G., "The Effectiveness of Regulation of Electric Utility Prices." *Southern Economic Journal*, April 1970, 365–75.

32. Mount, Timothy D., Duane Chapman and Timothy J. Tyrrell, "Electricity Demand in the United States: An Econometric Analysis." Oak Ridge National Laboratory, ORNL-NSF-49, June 1973.

33. Nelson, Jon P., Mark J. Roberts and Emsley P. Tromp. "A Test of Ramsey Pricing in Electric Utilities," unpublished working paper, Pennsylvania State University, December 1984.

34. Nelson, Randy A., "An Empirical Test of the Ramsey Theory and Stigler-Peltzman Theory of Public Utility Pricing." *Economic Inquiry*, April 1982, 277–90.

35. Panzar, John C. and Robert D. Willig, "Free Entry and the Sustainability of Natural Monopoly." *Bell Journal of Economics*, Spring 1977, 1–22.

36. Posner, Richard A. "Natural Monopoly and Its Regulation," in *The Crisis of the Regulatory Commissions*, edited by Paul W. MacAvoy. New York: W. W. Norton, 1970, pp. 30–38.

37. ———, "Taxation by Regulation." *Bell Journal of Economics and Management Science*, Spring 1971, 22–50.

38. Primeaux, Walter J. and Randy A. Nelson, "An Examination of Price Discrimination and Internal Subsidization by Electric Utilities." *Southern Economic Journal*, July 1980, 84–99.

39. Ross, Thomas W., "Uncovering Regulators' Social Welfare Weights." *Rand Journal of Economics*, Spring 1984, 152–55.

40. Stigler, George J. and Claire Friedland. "What Can Regulators Regulate: The Case of Electricity," in *The Crisis of the Regulatory Commissions*, edited by Paul W. MacAvoy. New York: W. W. Norton, 1970, pp. 39–52.

41. Taylor, Lester D., "The Demand for Electricity: A Survey." *Bell Journal of Economics*, Spring 1975, 74–110.

42. U. S. Department of Energy. "Cost and Quality of Fuels for Electric Utility Plants—1978." Washington, D.C.: USGPO, October 1979.

43. ———. "Statistics of Privately Owned Electric Utilities in the United States—1978." Washington, D.C.: USGPO, October 1979.