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ELECTRIC UTILITY FUEL CHOICE BEHAVIOR IN THE UNITED STATES

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I. INTRODUCTION

Electricity accounts for approximately 25 percent of the nation's annual energy consumption. While electricity can be produced in a wide variety of ways (fossil fuels, nuclear power, hydro, solar, geothermal), over 80 percent of it is produced with fossil fuels today. As a result, the aggregate effects of public policies aimed at altering fossil fuel consumption patterns in the United States depends on the nature of fossil fuel choice by the electric utility industry. Since many of the policies put forward by energy policy makers will, through their effects on fossil fuel prices, affect fuel utilization indirectly, a good understanding of the responsiveness of electric utilities to changing fossil fuel prices is of great importance.

There have been numerous studies of the production characteristics of the electric utility industry in the United States, virtually all of which specify a differentiable aggregate production function to describe the technology of electricity generation[1]. This specification seems to be unwarranted a priori since electricity generation is not characterized by a continuum of capital-labor-fuel ratios. Rather it appears that a firm can make use of a few discrete, fixed coefficient fuel burning technologies for generating electricity.

Techniques have been developed for model specification and estimation

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[1] See Galatin [3] for a summary of the literature.

of decision-making processes where the decision-maker is faced with discrete choices. One of these techniques -- conditional logit analysis -- has proved useful in econometric applications in areas ranging from transportation to revealed preferences for government bureaucracies[2]. This paper attempts to depart from the traditional (differentiable aggregate production function) specification of electricity production, using instead conditional logit analysis. The fuel choice of an electric utility for a new fossil-fuel base load steam-electric plant is analyzed to explicitly

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[2]

See McFadden [8] and [9].

[3]

Plant choice by electric utilities is intimately related to the cyclical character of electricity consumption. As a result of time of day and seasonal variation of electricity loads and the absence of easy storage, part of the utility's generating plant may be operated virtually continuously (base load), some of it for substantial fractions of the year (cycling) and some of it only when the load on the system is at it greatest (peaking). Base load plants normally have high construction costs and low operating costs, while peaking plants have low construction costs and high operating costs. The conditions determining the least cost combination of these different types of plants are well known (see Turvey [12]). In order to avoid problems associated with lumping together plants with vastly different utilization rates as well as dealing with the problem of changing plant mixes resulting from fuel price changes (most peaking plants are gas turbines so that once the decision to put a peaking plant is made, the fuel choice decision is met) we concentrate on the fuel choices associated with the construction of base load plants exclusively. This is obviously a simplication of the global optimization problem implied by the technology, but our discussion with the engineers who plan and build such plants indicates that this separation is a fairly accurate representation of the actual decision-making process.

Nuclear power plants present another problem. They tend to have even higher capital costs and much lower operating costs than do base load fossil fuel plants. In and of themselves they present no problem since the cost minimizing conditions can easily be adapted to handle them. However, separating the fossil fuel plant decision from the nuclear plant decision does not appear to be warranted. While our technique does not require us to make this separation (we could just use nuclear as an additional alternative) the nuclear plants installed so far have to some extent been experimental, have benefited from large government subsidies (both implicitly and explicitly) and have substantially longer construction times than fossil fuel plants. As a result, many of the nuclear plants that we observe today have not been added based on the same considerations that determine fossil fuel choice. We, therefore, concentrate on the period immediately preceeding the introduction of nuclear plants when the base load alternatives included only fossil fuels, and then, use our estimates to predict the effects of nuclear power availability based on expected cost estimates made in the late 1960's.

take account of the discreteness of fuel burning techniques available
to the firm[3]. For this purpose a probability model of the conditional
logit form is specified and estimated using maximum likelihood techniques.

The paper proceeds in the following way. The next section describes
the model of fuel choice behavior hypothesized; section three discusses
the estimation of the values of characteristics which determine fuel choice;
the fourth section presents maximum likelihood estimates of the conditional
logit specification based on a sample of individual fuel choice decisions;
section five discusses the responsiveness of fuel choice to changing fuel
prices and the availability of a nuclear alternative for some representative
plants in the United States; and a final section contains concluding remarks.

II. THE MODEL

The firm building a new fossil fuel base load steam-electric plant is assumed to face a set of a maximum of seven alternative techniques for generating electricity. Each technique is associated with a different combination of the three fossil fuel inputs: coal, oil, natural gas[4]. For fixed output each technique has a vector of expected cost characteristics x(x_i for the ith technique) upon which the firm's choice is based. The firm's preferences regarding generating technique are described by a decision index C of the following form[5]:

$$(1) \qquad C = C(x) + \epsilon(x)$$

where ϵ (x) are random disturbances with some probability distribution and $C(x)$ is non-stochastic. A decision-maker faced with the set of k alternatives will choose alternative i if: $C(x_i) + \epsilon(x_i) < C(x_j) + \epsilon(x_j)$ for all $j \neq i$. The probability that he will do so is thus:

$$(2) \quad P_i = \text{Prob } [C(x_i) + \epsilon(x_i) < C(x_j) + \epsilon(x_j)] \qquad \text{for all } i \neq j$$

$$= \text{Prob } [\epsilon(x_i) - \epsilon(x_j) < C(x_j) - C(x_i)] \qquad \text{for all } i \neq j$$

Let $F(\epsilon_1, \ldots, \epsilon_j)$ represent the cumulative joint distribution function of the disturbances and let F_i denote the derivative of F with respect to the ith argument. Then:

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[4] The seven fuel burning techniques are: (1) coal; (2) oil; (3) gas; (4) coal-oil; (5) coal-gas; (6) oil-gas; (7) coal-oil-gas .

[5] C can also be thought of as a cost function where the firm's goal is to minimize cost. Calling C a decision index is less restrictive since it is not always clear that regulated electric utilities are cost minimizers, and cost minimization is not required for this model (see Averch and Johnson [1]). We examine below whether the estimated decision index is consistent with cost minimization by these regulated firms.

$$(3) \quad P_i = \int_{-\infty}^{\infty} f_i \left[\varepsilon_1 + C(x_1) - C(x_i), \ldots, \varepsilon_k + C(x_k) - C(x_i) \right] d\varepsilon$$

McFadden [2] has shown that if the decision process can be characterized as satisfying: 1) the independence of irrelevant alternatives; 2) positivity; 3) irrelevance of alternative set effects or alternatively that the $\varepsilon(x)$ are distributed with the Weibull distribution, $\varepsilon \sim e^{-e^{-\varepsilon}}$, then equation(3) can be rewritten as:

$$(4) \quad P_i = \frac{e^{-C(x_i)}}{\sum_{j=1}^{k} e^{-C(x_j)}}$$

which is the conditional logit model. This conditional logit model can be estimated by maximum likelihood techniques yielding estimates with desirable large sample properties.

Each alternative has a set of expected cost characteristics:

1. Fuel cost (\$) per thousand kwh = $FCOST_i^*$.

2. Non-fuel production expenses (\$) per thousand kwh = $PRODE_i^*$.

3. Annualized capital cost (\$) per kilowatt of capacity = K_i^*.

where $FCOST_i^*$, $PRODE_i^*$, K_i^* are all in current price terms [6].

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[6] We have expressed the annualized capital cost component in dollars per kilowatt since it is in these units that capital costs of generating capacity are usually discussed. We could easily have expressed this figure in terms of kilowatt hours by recognizing that there are 8760 hours in a year and (let's say) an 80% utilization factor. Capital cost per kwh would then simply be the cost figure that we use divided by 7008. Since we assume the intended utilization factor for base load equipment is constant across firms, it is not necessary to perform the transformation for it would have no effect on the estimated probabilities. We have also experimented with varying the utilization factor across firms and deriving the associated capital cost per kwh. See footnote 30.

Assume that the decision index C is linear in its cost charac-
teristics[7]. Then we may write the probability that a firm will choose
to build a plant using technique (i) as:

$$(5) \quad P_i = \frac{e^{\beta_1 \, FCOST_i^* + \beta_2 \, PRODE_i^* + \beta_3 \, K_i^*}}{\sum_{j=1}^{k} e^{\beta_1 \, FCOST_j^* + \beta_2 \, PRODE_j^* + \beta_3 \, K_j^*}}$$

It may be that there are "technique specific" attributes associated
with each of the alternative techniques. Each individual technique may
have inherent characteristics that are unmeasurable. This can be handled
by including dummy variables in the characteristic set, where a technique
specific dummy for alternative m equals one when $j = m$ or $i = m$ in
equation (4), and zero otherwise. The decision index can now be written
as:

$$(6) \quad C_i = \beta_1 \, FCOST_i^* + \beta_2 \, PRODE_i^* + \beta_3 \, K_i^* + \alpha_2 \, DUM2 + \alpha_3 \, DUM3 \ldots + \alpha_7 \, DUM7$$

where DUM2 through DUM7 are technique specific dummies for alternatives two
through seven[8]. The model will be estimated with a decision index of the
form of (5) above.

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[7]
If C is interpreted as a cost function, then linearity implies that each
technique's underlying production function is of the Leontief form: i.e.,
each technique is a fixed coefficient technology with no factor substitution
possible. The conditional logit model of this paper assumes that electric
utilities are faced with discrete fixed-coefficient fuel-burning techno-
logies; thus, C if it is interpreted as a cost function, should be of a
linear form. The linear C has therefore been preferred for estimation
purposes, although a decision index linear in the logs has been used for
model estimation and has been found to produce a less satisfactory pattern
of estimated coefficients.

[8]
Note: There can be no more than six dummies (one less than the total
possible alternative choices) because the sum of the probabilities
must be unity. The obvious problem associated with taking this approach
is that the inclusion of "technique specific" dummy variables in place
of an exhaustive specification of the characteristic set makes it very
difficult to forecast the effect of "abstract" alternatives having the
same characteristic set as the known alternatives. Since one of the
major attractions of the conditional logit specification is the ability
to predict the effects of the introduction of new alternatives, this is
certainly a major drawback. One could assume that the abstract alter-
native did not have a technique specific effect or that it is the same
as one that has been estimated for a known alternative. Such assumptions
may not be satisfactory in many situations and as a result a complete
specification of the characteristic space should be sought.

III. ESTIMATION OF THE EXPECTED COST CHARACTERISTICS

The conditional logit model of electric utility fuel choice is
estimated for 67 plants, each with over 200 megawatts of capacity, built
in the period 1952-1965. This period was chosen because: 1) it covers
a large part of the post-war era; 2) environmental restrictions which
appear to have strong non-cost oriented effects on fuel choice behavior
were not yet important; 3) nuclear power had not yet become an
important base load alternative.

Estimation of the conditional logit model with a decision index
described by equation (6) requires data on the expected cost character-
istics - $FCOST^*$, $PRODE^*$, K^* - for all available techniques facing the
electric utility firm. However, the electric utilities only report cost
characteristics of the generating technique that was actually chosen for
their new plant; no direct data on cost characteristics of non-chosen
alternatives is available.

This problem of missing cost data is handled in the following way:
we view the expected cost characteristics of a particular technique which
are in nominal terms, as composed of a technologically determined real
component multiplied by an expected price -- whether it be the cost of
fuel, construction, capital or labor. Estimates of the real and expected
price components of cost characteristics can be obtained for all techniques
facing the firm. These estimates can then be used to construct data for
the required $FCOST^*$, $PRODE^*$, and K^* variables. The procedure followed in
this section to obtain these estimates is outlined in the table below.
For example, in each of the 67 plants in the sample, we derive an estimate
for each technique of the real quantity of fuel energy required per kilowatt-
hour of electricity generation. This is then multiplied by an estimate of
the expected price of an energy unit of the particular fuel used in each
technique to create the required $FCOST^*$ variable.

ESTIMATION OF EXPECTED COST CHARACTERISTICS

	Real Component (1)	Expected Price (2)	Expected Cost (1) x (2)
FUEL	Heat Rate - BTU/KWH (HRATE)	Fuel Price-$/MBTU (PF^*)	Expected Fuel Cost $/MKWH $(FCOST^*)$
NON-FUEL-EXPENSES	Real Cost/MKWH (PROD)	Price Deflator $(PPROD^*)$	Expected Non-Fuel Production Expenses $/MKWH $(PRODE^*)$
ANNUAL CAPITAL COST	Real Cost/KW (KTOT)	Cost of Capital (PK^*)	Expected Annual Cost of Capital $/KW- YEAR (K^*)

THE REAL COST COMPONENT OF ALTERNATIVE TECHNIQUES OF
ELECTRICITY GENERATION :

The technologically determined real cost component can be estimated as follows. Deflated cost data from the sample steam-electric plant's second year of operation[9] is used in experiments with ordinary least squares regression models describing average real cost characteristics of different fuel-burning technologies. Different functional forms — linear, semi-log, double-log — and different variables — plant size, building type, utilization rate, etc. — are tested in order to produce equations best describing real cost characteristics. These equations are then used to create real cost estimates (assuming that the plant is to be used at full capacity) of different fuel-burning techniques for a plant with the same size and building type as those of the sample plants.

We turn now to the regression equations that best describe the technologically determined real components of fuel cost, non-fuel production expenses and capital costs[10].

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[9] The second year of plant operation has been chosen because many bugs are not eliminated until the second year making data from the first year of operation unrepresentative of true expected costs, and while later years of plant operation may be influenced by new technological improvements not anticipated by the utility firm. A larger sample of 73 plants was used for evaluating cost components not involving distributed lags. This sample includes the 67 plants used in the conditional logit estimation plus 6 plants built in the 1950-1951 period. These six were not used in the conditional logit analysis because price data were not available for distributed lag estimation.

[10] A discussion of the data used in these regressions will be found in the Appendix.

F U E L   C O S T :

The quantity of fuel energy required for the generation of electricity is characterizied by the heat rate of the generating plant: the number of BTU's of fuel energy necessary for generation of one kilowatt-hour of electricity. The desired FCOST* variable -- the fuel cost per thousand kilowatt-hours of electricity -- equals the heat rate multiplied by the price per thousand BTU's of fuel.

A heat rate equation was specified with the natural logarithm of the heat rate (LNHRATE) being a linear function of: 1) the natural log of the plant utilization rate (LNFACTOR) -- to take account of possible capacity utilization effects on productivity; 2) the natural log of the capacity of the plant in megawatts (LNMW) -- to allow for possible returns to scale; 3) a time trend variable (TIME = 1 for 1950, 2 for 1951, etc.) that allows for technological change over the period and 4) six dummy variables for the alternative fuel-burning techniques (D2, D3, ..., D7)[11,12].

The engineering literature indicates that there should be some scale economy effect for the heat rate, that there has been some technological improvement over time and that coal should have a lower heat rate than the other techniques, although the difference would be small[13]. Increased capacity utilization might also result in a lower heat rate. We therefore expect the coefficients of the size, time trend and plant factor variables to be negative, and the coefficients of the dummy variables to be positive.

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[11]
  D2 = 1 if the technique is oil burning; 0 otherwise.
  D3 = 1 if the technique is gas burning; 0 otherwise.
  D4 = 1 if the technique is coal-oil burning; 0 otherwise.
  D5 = 1 if the technique is coal-gas burning; 0 otherwise.
  D6 = 1 if the technique is oil-gas burning; 0 otherwise.
  D7 = 1 if the technique is coal-oil-gas burning; 0 otherwise.
    If all the dummies = 0, then the technique is coal burning.

[12]
The double log regression specification was superior to the simple linear and semi-log forms for this and all the following regressions describing real costs. T-statistics were increased substantially with the double log regressions.

[13]
See National Economic Research Associates [11].

Initial estimates[14] did not yield coefficients for the dummy variables with uniform positive signs and none of them were statistically significant, while the plant factor coefficient was extremely small relative to its standard error. The LNFACTOR and dummy variables were therefore dropped from the equation and the regression was reestimated with the following results:

(7)   LNHRATE = 9.8729 − .0989 LNMW − .008499 TIME
                  (22.28)   (−1.30)   (−1.16)

$$R^2 = .0698 \quad \text{Standard Error (SE)} = .2736$$
$$\text{degrees of freedom (d.f.)} = 70$$

The figures in parentheses are (t-statistics) of the coefficients[15].

The signs of the scale and time variables are as expected, yet though the estimated coefficients are greater than their standard errors, they are not significant at the 5% level. These results indicate that the heat rate of a new generating plant added during the period 1950–1965 was essentially constant, although there is some evidence of small increasing returns to scale and technological change. Although _average_ heat rates for electric utilities declined until about 1970 it appears that most of the break-throughs in boiler efficiency were made before 1950. The decline in average heat rates reflects the fact that the generator stock turns over slowly and is not indicative of continuous technological change in electricity generation from fossil fuels, as has sometimes been asserted.

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[14]   LNHRATE = 10.0737 − .0504 LNFACTOR − .0966 LNMW − .0093 TIME +
                  (13.64)   (−.41)   (−1.18)   (−1.15)

        + .0197 D2 + .0299 D3 + .0036 D4 − .0085 D5 − .0149 D6 − .0621 D7
            (.16)   (.17)   (.02)   (−.07)   (−.11)   (−.21)

$$R^2 = .0749 \quad \text{SE} = .2876 \quad \text{d.f.} = 63$$

None of the alternative specific dummies has a coefficient greater in absolute value than one-quarter of its standard error.

[15] Recall a 73 plant sample is used to estimate this equation.

NON-FUEL PRODUCTION EXPENSES

Non-fuel production expenses per thousand kwh (for the second year
of plant operation) have been obtained in real terms for each sample
plant by deflating the plants' nominal production expenses by an electric
utility labor cost deflator (see Appendix).

The natural log of the real non-fuel production expenses per thousand
kilowatt-hours (LNPROD) was assumed to be a linear function of the same
variables affecting heat rate: LNFACTOR, LNMW, TIME and D2 through D7.
Increased utilization of a plant should lower production costs of a kilowatt-
hour of electricity, while productivity should increase over time as a re-
sult of technological progress and possibly a better trained workforce;
thus, the coefficients of LNFACTOR and TIME should have a negative sign.
Increasing returns to scale are a much discussed aspect of electricity
generation, and if this is in fact true then the LNMW coefficient should be
significantly negative.

The regression results are the following:

(8) LNPROD = 4.3361 − .7787 LNFACTOR − .2265 LNMW − .0397 TIME −

   (5.38)   (−5.78)   (−2.52)   (−4.46)

   − .2476 D2 − .4632 D3 + .2071 D4 + .0525 D5 − .4813 D6 − .0019D7

   (−1.86)   (−2.39)   (.88)   (.38)   (−3.44)   (−.01)

$$R^2 = .5546 \quad SE = .3167 \quad d.f. = 63$$

Considering the cross-section nature of this regression, the results
are excellent. The LNFACTOR, LNMW and TIME regression coefficients are all
significant at the one percent level and are of the expected sign. Produc-
tivity increases of about four percent per annum are indicated and the
evidence supporting increasing returns to scale is quite strong. Furthermore,

the dummy coefficients are invariant to scale effects[16] and they show
that techniques not using coal have lower production expenses; of these
the gas techniques have lower costs than the oil techniques. The large
bulk of coal and the problem of its waste products give it the most costly
non-fuel production expenses. Oil does not have the bulk of coal, yet
still requires substantial handling. Natural gas, however, which can be
piped right into the plant, presents the least difficulties of handling
and waste disposal. These "stylized facts" are all consistent with our
regression results.

CAPITAL EXPENDITURES

The capital expenditures for the 63 plants have been deflated by a
utility construction price deflator (see Appendix). The natural logarithm
of the deflated capital expenditures (LNKTOT) was assumed to be a linear
function of LNMW, TIME, D2 through D7, and two new dummies describing the
type of plant structure, SEMI-OD and OD[17]. Increasing returns and techno-
logical progress would indicate negative signs for the LNMW and TIME
coefficients. The more outdoor the plant structure, the cheaper it should
be to build; the coefficients of SEMI-OD and OD should thus be negative
with the OD coefficient having larger absolute value.

The real capital expenditures may be heavily influenced by the
region in which the plant is built. Different climates require a different
structural plant design: a plant that will encounter heavy snowfall must

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[16]
   The sample was split into plants 300 megawatts and under, and those over
   300 megawatts. A "Chow" test could not reject the null hypothesis that
   the dummy coefficients were the same for plants in the different size
   groupings. $F(4,61) = 1.23$, while the critical F for rejection of H_0 at
   the 5% level is 2.52. (only five techniques were used for plants
   300 megawatts and under, so only four of the six dummy coefficients
   could be tested for stability).

[17]
   SEMI-OD = 1 if the structure is semi-outdoor; 0 otherwise.
       OD = 1 if the structure is outdoor; 0 otherwise.

have roofing at greater strength, while a plant in a hurricane or tornado prone area must be able to withstand high winds. Varying quantities of material and labor will be necessary for construction of a steam-electric plant in different areas of the U.S. and this will be reflected in construction costs. To adjust for these effects a LNKTOT regression was also run with eight regional dummies[18]. Regression results for both specifications are reported below:

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[18]

NE = 1 if the plant was built in the Northeast region
(Mass., Conn., R. I., Maine, N.H., Vermont)
0 otherwise.

MA = 1 if the plant was built in the Middle Atlantic region
(N.Y., N.J., Pa.)
0 otherwise.

ENC = 1 if the plant was built in the East North Central region
(Ohio, Ind., Ill., Mich., Wisc.)
0 otherwise.

WNC = 1 if the plant was built in the West North Central region
(Minn., Iowa, Mo., N. Dakota, S. Dakota, Neb., Kansas).
0 otherwise.

SA = 1 if the plant was built in the South Atlantic region
(Del., Md., Wash D. C., W. Va., N.C., S.C., Ga., Fla., Va.)
0 otherwise.

ESC = 1 if the plant was built in the East South Central region
(Ky., Tenn., Ala., Miss.)
0 otherwise.

WSC = 1 if the plant was built in the West South Central region
(Ark., La., Okla., Texas).
0 otherwise.

MT = 1 if the plant was built in the Mountain region.
(Montana, Idaho, Wyo., Colo., N. Mex., Ariz., Utah, Nevada).

If all the regional dummies = 0, then the plant was built in the Pacific region (Washington, Oregon, California).

(9) LNKTOT = -3.6709 - .0656 LNMW - .0514 TIME - .1248 SEMI-OD

         (-13.68)   (-1.44)   (-10.94)   (-1.51)

         - .1780 OD - .1239 D2 - .0255 D3 + .0522 D4

          (-2.97)   (-1.58)   (-.23)   (.44)

         + .2395 D5 - .0990 D6 + .0464 D7

          (2.98)   (-1.30)   (.29)

$$R^2 = .7902 \quad SE = .1582 \quad d.f. = 62$$

(10) LNKTOT = -3.6243 - .0809 LNMW - .0481 TIME - .1262 SEMI-OD

         (-12.87) (-1.79)   (-10.02)   (-1.34)

         -.1828 OD - .0601 D2 -.3416 D3 + .0598 D4 + .2293 D5

          (-2.82)   (-.65)   (-1.68)   (.53)   (2.66)

         -.1540 D6 - .0165 D7 - .1160 NE + .0935 MA + .0335 ENC

          (-1.36)   (-.10)   (-.75)   (.80)   (.27)

         +.0757 WNC - .0997 SA + .0738 ESC + .3254 WSC - .0054 MT

          (.39)   (-.86)   (.57)   (1.95)   (-.03)

$$R^2 = .8429 \quad SE = .146621 \quad d.f. = 54$$

In both regressions the LNMW, TIME, SEMI-OD and OD all have expected signs, while the SEMI-OD and OD coefficients are of the expected relative magnitude. Increasing returns are not as strong for plant capital expenditures as for production expenses, and the LNMW coefficients are not even significant at the five percent level in the LNKTOT regressions. There appears to be little gain from increased scale in the capital cost area[19]. Technological change in steam-electric plant construction is on the order of five percent per year.

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[19] This is consistent with findings in the literature regarding plants of the size and construction date we have chosen here. See for example Huettner [5].

Problems of collinearity between the fuel and regional dummies make it difficult to determine the exact influence of the different fuel-burning techniques on construction costs. In both regressions the technique dummy coefficients are unaffected by the size of the plant[20], and it seems that plants not burning coal are cheaper to build. Plants using coal require storage yards that should make the capital costs of these plants higher. The regressions indicate that multi-fuel coal plants are more costly to build than single fuel plants, especially plants of the coal-gas variety.

Since regional effects are expected to influence construction costs and the pattern of coefficients of the regression with regional dummies seems sensible, this regression probably better reflects the differing construction costs of alternative fuel-burning techniques. Thus equation (10) is used to construct the K_1^* variable for the conditional logit estimates reported later.

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[20]
Tests similar to the "Chow" test described in footnote [16] could not reject the hypothesis that the dummy coefficients were the same for plants over and under 300 megawatts. $F(4,60) = 1.52$ for the regressions without regional dummies (critical F at 5% = 2.52) while $F(4,52) = 1.28$ for regressions with regional dummies (critical F at 5% = 2.55).

PRICE EXPECTATIONS AND EXPECTED COST CHARACTERISTICS OF PLANT ALTERNATIVES:

Since price data for the non-chosen alternatives is not available from the electric utilities, we will assume that expected prices for different techniques are adequatedly described by prices in the sample plant's state or region. Furthermore, past prices influence expectations of future price, and thus expected prices for alternative techniques are modeled as a distributed lag on past prices in that plant's state or region.

For each sample plant the expected fuel price used in calculating $FCOST_i^*$ for each technique i is:

$$(11) \quad PF_i^* = \sum_{j=0}^{\ell} a_j \, PF_{i,t-j}$$

where

PF_i^* = expected price per BTU of fuel used in technique i.

$PF_{i,t-j}$ = technique i's fuel price per BTU[21] in the plant's state in year t-j.

t = year when the electric utility makes its decision on fuel-burning technique for the sample plant.

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[21] The model presented in this paper does not determine the fuel mix of a multi-fuel plant. The $PF_{i,t-j}$ variable for multi-fuel techniques is calculated using the sample average fuel mix for the multi-fuel plants corresponding to a particular fuel burning technique. In gas interruptible multi-fuel plants the average fuel mix in energy units is 45.49% gas and 54.51% to alternative fuels. (In the coal-oil-gas case it is 1% coal, 53.51% oil and 45.49% gas). The coal-oil mix is 99.1% coal and .9% oil.

Each plant's corresponding expected prices for constructing $PRODE_1^*$ and K_1^* are:

(12) $\quad PPROD^* = \sum_{j=0}^{M} b_j \, PPROD_{t-j}$

(13) $\quad PK^* = \sum_{j=0}^{N} c_j \, PK_{t-j}$

where

$PPROD^*$ = expected price deflator for non-fuel production expenses.

$PPROD_{t-j}$ = price deflator for non-fuel production expenses in the sample plant's region in year t-j.

PK^* = expected user cost of units of plant capital.

PK_{t-j} = user cost of units of plant capital in the sample plant region in year t-j.[22]

Each sample plant's expected cost characteristic variables $FCOST_1^*$, $PRODE_1^*$, and K_1^* for each technique used in estimating the logit model can now be written as the multiplication of the estimated technologically

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[22] The user cost of capital measure is of the Hall-Jorgenson [4] type.

$$PK_{t-j} = \frac{pc_{t-j} \, (r_{t-j} + \delta) \, [1 - k_{t-j} - u_{t-j} z_{t-j} + u_{t-j} z_{t-j} k_{t-j}]}{1 - u_{t-j}}$$

for t-j < 1964

pc_{t-j} = price deflator for plant construction in the sample plant's region in year t-j.

r_{t-j} = user cost of funds in year t-j.

d = replacement rate

u_{t-j} = corporate income tax rate in year t-j.

k_{t-j} = effective tax credit in year t-j.

z_{t-j} = present value of depreciation scheme in year t-j.

The data used for construction of this variable is described in the Appendix.

determined real component and an expected price. Therefore,

(14) $FCOST_i^* = HRATE_i \times PF_i^* = \sum_{j=0}^{\ell} a_j \, HRATE_i \times PF_{t-j} = \sum_{j=0}^{\ell} a_j \, FCOST_i^j$

where

$FCOST_i^j = HRATE_i \times PF_{i,t-j}$

$HRATE_i$ = estimate of HEAT RATE from equation (7).

(15) $PRODE_i^* = PROD_i \times PPROD^* = \sum_{j=0}^{M} b_j \, PROD_i \times PROD_{t-j} = \sum_{j=0}^{r} b_j \, PRODE_i^j$

where

$PRODE_i^j = PROD_i \times PPROD_{t-j}$

$PROD_i$ = estimate of deflated non-fuel production expenses from equation (8).

(16) $K_i^* = KTOT_i \times PK^* = \sum_{j=0}^{N} c_j \, KTOT_i \times PK_{t-j} = \sum_{j=0}^{N} c_j \, K_i^j$

where

$K_i^j = KTOT_i \times PK_{t-j}$

$KTOT_i$ = estimate of deflated capital expenditures from equation (10).

We now turn to the estimation of the conditional logit model. However, we should take note of one remaining problem with the fuel cost data; the statewide gas prices available do not accurately reflect the true opportunity cost of obtaining gas for a new steam-electric plant. Gas is not always available because of a lack of pipelines to supply the new plant. Furthermore, gas companies consider consumers and industry their primary market. They usually sell gas to electric utilities only on a residual basis: i.e., they supply the electric utility only when their other customer's demands have been satisfied. Gas price data for electric utilities tend to reflect the interruptible nature of these contracts. Gas rationing as a result of F.P.C. price controls instituted in the early 1960's also is a factor[23].

The peculiarities of the natural gas market cause two major problems for the conditional logit model estimation in this paper: 1) the observed gas price understates the market clearing price of natural gas; there is excess demand at observed prices and utilities probably can't get all they would like. If some measure of gas availability were available, then this could be incorporated into the conditional logit model. Unfortunately, no such measure exists. 2) Natural gas is often sold to the electric utilities on an interruptible basis (gas is only available at the times of the year when there is low consumer and industrial demand). The electric utility is thus forced to build a plant that burns some other fuel besides gas, even though a gas-only steam-electric plant would be preferred. The cost-oriented conditional logit model presented in this paper is not designed to handle the modeling of this situation in any detail.

A cost minimizing firm should not prefer one non-gas burning alternative technique to another on a basis other than cost[24]. On a priori

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[23]

See MacAvoy and Pindyck [7].

[24]

It is true that technique attributes besides the current and capital expense characteristics included in our conditional logit model could influence fuel choice decisions. Yet, in the period before 1965 the pollutants of coal and oil burning techniques were not a major factor in the choice of fuel, and other non-cost quantifiable attributes of coal and oil burning techniques should only have a negligible effect on the fuel choice decisions.

grounds, technique specific dummies for non-gas alternatives -- oil and coal-oil -- should not be included in the conditional logit model[25]. Yet, the inadequacies of the available gas price data requires estimation of the conditional logit model with technique specific dummies for the four gas-burning alternatives. These dummies (DUM-G, DUM-CG, DUM-OG, DUM-COG) should correct somewhat for the unmeasurable effects influencing decisions to choose gas-burning techniques, and will give some measure of the availability situation in the natural gas market as well.

The conditional logit model to be estimated is therefore:

$$(17) \quad P_i = \frac{e^{\beta_1 FCOST_i^* + \beta_2 PRODE_i^* + \beta_3 K_i^* + \alpha_3 DUM\text{-}G + \alpha_5 DUM\text{-}CG + \alpha_6 DUM\text{-}OG + \alpha_7 DUM\text{-}COG}}{\sum_{q=1}^{k} e^{\beta_1 FCOST_q^* + \beta_2 PRODE_q^* + \beta_3 K_q^* + \alpha_3 DUM\text{-}G + \alpha_5 DUM\text{-}CG + \alpha_6 DUM\text{-}OG + \alpha_7 DUM\text{-}COG}}$$

P_i is the probability of choosing the ith alternative when the utility firm is faced with k possible alternatives $(k \leq 7)$[26].

Substituting equations (14), (15), and (16), into (17) gives us the following logit model used for estimation:

$$(18) \quad P_i = \frac{e^{[\beta_1 \sum_{j=0}^{\ell} a_j FCOST_i^j + \beta_2 \sum_{j=0}^{M} b_j PRODE_i^j + \beta_3 \sum_{j=0}^{N} c_j K_i^j + \alpha_3 DUM\text{-}G + \alpha_5 DUM\text{-}CG + \alpha_6 DUM\text{-}OG + \alpha_7 DUM\text{-}COG]}}{\sum_{q=1}^{k} e^{[\beta_1 \sum_{j=0}^{\ell} a_j FCOST_q^j + \beta_2 \sum_{j=0}^{M} b_j PRODE_q^j + \beta_3 \sum_{j=0}^{N} c_j K_q^j + \alpha_3 DUM\text{-}G + \alpha_5 DUM\text{-}CG + \alpha_6 DUM\text{-}OG + \alpha_7 DUM\text{-}COG]}}$$

Maximum likelihood methods can be used to estimate a conditional logit model described by equation (18), and computer programs are available

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[25]

When oil and coal-oil technique specific dummies were included in the model, as expected, their coefficients were not significantly different from zero.

[26]

When one fuel was not used for electricity generation in a state, all alternative techniques using this fuel were not considered to be in the choice set. The firm may thus be faced with less than seven possible alternatives for electricity generation.

to estimate this model[27]. There are problems of collinearity of the lagged
variables and the possible large number of lagged coefficients to be
estimated. These problems can be avoided through use of the polynominal
distributed lag technique. The lag coefficients are assumed to lie on
an nth degree polynomial which allows the replacement of the lagged variables
by a smaller number of "scrambled" variables equal to a linear combination
of the lagged variables.[28] Estimation of the conditional logit model can
now proceed, and by unscrambling of the "scrambled" variables, estimates
of the original lag coefficients can be obtained. Assymptotic standard
errors can also easily be derived.

We can test hypotheses concerning the maximum likelihood estimates
of non-linear models -- conditional logit is a member of this class --
by using likelihood ratio tests. If we wish to test the null hypothesis
that certain constraints on the coefficients are valid, we compute the
maximized value of the likelihood function for the constrained model (L^{**})
and the unconstrained model (L^{*}).

$$\lambda = L^{**}/L^{*}$$

and $-2 \log \lambda$ is asymptotically distributed as X^2 with q degrees of freedom,
where q equals the number of constraints. The null hypothesis is rejected
for $-2 \log \lambda$ greater than the appropriate critical value of the X^n dis-
tribution.

The standard errors reported for conditional logit estimates are
not exact in small samples; they are correct only asymptotically. T-tests
can be performed on the coefficients of the conditional logit model using
the reported standard errors, though the significance levels are only
accurate as the sample size goes to infinity. Asymptotically the T-test
and likelihood ratio test are exactly equivalent.

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[27] The program used to estimate this model was developed at Berkeley
by Daniel McFadden and his associates. Hal Varian was kind enough
to supply us with the coded deck.

[28] See Jan Kmenta [13] p. 492-495.

If the firm is a cost minimizer a technique with lower costs should more likely be chosen by the utility decision maker. It is expected that the coefficients of FCOST*, PRODE* and K* (β_1, β_2, β_3) will be negative in the model described by (17). Furthermore, since a more current price should have a stronger effect on expectations of future prices — i.e., $a_j > 0$ and $a_j > a_j'$, if $j < j$; $b_j > 0$ and $b_j > b_j'$ if $j < j$; and $c_j > 0$, $c_j > c_j'$ if $j < j'$ — the coefficients on the lagged FCOST, PRODE and K variables in (18) ($\beta_1 a_j$, $\beta_2 b_j$, $\beta_3 c_j$) should be negative and decline in absolute value as the lag increases. The technique specific dummies for gas-using alternatives should also have negative signs. Understatement of the opportunity cost of natural gas by the available data makes gas-using alternatives look more desirable than is actually the case; this must be compensated for by negative technique specific dummies on gas-using alternatives.

One multi-fuel gas technique should not be preferred to another for non-cost reasons, thus the coefficients on multi-fuel gas techniques should be equal. A substantial difference between the pure gas alternative specific dummy and the multi-fuel gas alternative specific dummies may arise because negotiating a non-interruptible gas supply contract with the natural gas companies may be extremely difficult. The probability of choosing a pure gas alternative may thus be lower than a multi-fuel gas alternative when cost characteristics derived from available data are similar. The pure gas alternative specific dummy might well be more negative than the multi-fuel gas alternative specific dummies as a result.

Construction of the PRODE^j and K^j variables is such that there is not enough power in the data to enable us to accurately describe the lag structure of the PRODE* and K* variables. In fact there is no significant improvement in fit when lagged variables PRODE^1, PRODE^2, ... or K^1, K^2, ... are added to a conditional logit model estimated solely with PRODE^0 and K^0 as the variables related to expected non-fuel production expenses and annualized capital costs. In the conditional logit estimates

reported below only PRODE^O and K^O are included in the conditional logit model and thus the polynomial distributed lag formulation was not required in estimation of the coefficients of these variables.

Experiments with different assumptions about the year of the plant fuel choice decision indicate that the best fits and most sensible estimated lag patterns appear when it is assumed that the decision on fuel-burning technology is made two years before plant completion. This corroborates nicely with engineers' estimates that plant fuel choice is made when boiler construction begins, about two years before plant completion[29]. (Recall that t in the distributed lag equations refers to the number of years before actual operation that the fuel choice decision is made).

The best estimate of the conditional logit model (18) was achieved with a fuel choice decision made two years before plant completion, a current FCOST variable and FCOST lagged two periods, and the coefficients of the FCOST variables assumed to lie on a second degree polynomial with an end-point constraint (i.e., $a_3 = 0$). This appears as Model 1 in Table 1.

Our initial estimates of (18) reported as Model # 1 in Table 1 yielded significant estimates with the correct signs for the coefficients of the expected fuel costs and expected non-fuel production expense variables. The coefficient of the expected capital cost variable was not significantly different from zero at any reasonable significant level[30], however.

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[29] . This estimate was kindly supplied to us by Stone and Webster Appraisal Corporation, Boston, Massachusetts.

[30]
Conditional logit models have been estimated with other expected capital cost variables which were constructed in one case from a LNKTOT regression without regional dummies and in other cases from separate regressions of the equipment and structures components of capital expenditures. The coefficients never enter significantly with the correct negative sign and are usually of the wrong sign. Also experiments which allow for planned use of plant at below full capacity using actual second year plant utilization as an estimate of planned capacity utilization still produced an insignificant capital cost coefficient of the wrong sign. Furthermore, the coefficient estimates were not particularly sensitive to different assumptions in computing the Hall-Jorgenson cost of capital measure.

TABLE 1* - CONDITIONAL LOGIT COEFFICIENT ESTIMATES

(a's lie on 2nd degree polynomial with a_3 constrained to equal zero; t= plant completion year-2)

MODEL	FCOST^0 ($\beta_1 a_0$)	FCOST^1 ($\beta_1 a_1$)	FCOST^2 ($\beta_1 a_2$)	COEFFICIENTS OF PRODE^0 ($\beta_2 b_0$)	COEFFICIENTS OF K^0 ($\beta_3 c_0$)	Gas Technique Dummy (DUM-G)	Coal-Gas Technique Dummy (DUM-CG)	Oil-Gas Technique Dummy (DUM-OG)	Coal-Oil-Gas Technique Dummy (DUM-COG)	Dummy for All Gas Using Techniques (DUM-AG)
1)	-2.4038 (-1.7968)	-1.6219 (-2.9564)	-.8207 (-1.0058)	-9.0728 (-2.3956)	.0839 (.1742)	-9.9168 (-3.5358)	-2.7765 (-1.1709)	-2.8068 (-3.4298)	-1.1523 (-1.0404)	
	$\beta_1 \sum_{i=0}^{2} a_i = -4.8464$ (-4.1866)			LOG LIKELIHOOD = -46.2921		LIKELIHOOD RATIO INDEX** = .58253	d.f. = 302			
2)	-2.3726 (-1.7889)	-1.6139 (-2.9566)	-.8231 (-1.0074)	-8.5299 (-3.9927)		-10.2023 (-4.4716)	-2.3793 (-4.0041)	-2.8603 (-3.7720)	-1.1749 (-1.0707)	
	$\beta_1 \sum_{i=0}^{2} a_i = -4.8096$ (-4.2555)			LOG LIKELIHOOD = -46.3076		LIKELIHOOD RATIO INDEX = .58239	d.f. = 303			
3)	-2.3472 (-1.8141)	-1.5533 (-2.9079)	-.7729 (-.4684)	-7.5106 (-4.5910)		-7.2060 (-3.6495)				-2.4412 (-5.1709)
	$\beta_1 \sum_{i=0}^{2} a_i = -4.6754$ (-4.2178)			LOG LIKELIHOOD = -47.0105		LIKELIHOOD RATIO INDEX = .57605	d.f. = 305			

* asymptotic t-statistics in parentheses

** The likelihood ratio index equals the fractional increase in the log likelihood in going from an equiprobable model to the estimated conditional logit model; it is a measure of goodness of fit.

The inability to obtain a significant capital cost coefficient is very troublesome. The problem may be statistical. Equation (10) shows that the gas burning technique tends to have lower capital costs than the coal or oil burning techniques. Other things being equal the gas burning technique should be favored. At the same time, the observed cost of natural gas is far below its opportunity costs, so that the observed fuel prices would indicate more of a preference for gas than can be realized in the market. The introduction of a dummy variable for gas burning techniques to deal with this problem essentially confounds an "availability" phenomenon that works against gas and a capital cost phenomenon that works in favor of gas, making it impossible to identify a capital cost coefficient. On the other hand, since firms are regulated public utilities, this result may also be evidence of Averch-Johnson [1] type biases. In particular, the nature of rate of return regulation may give firms an incentive to choose a technique that has higher capital costs relative to fuel and operating costs than would be indicated by pure cost minimizing considerations. Finally, it has been suggested to us that at least during the period of our sample, firms employed a rule of thumb, choosing the fuel with the lowest fuel and production costs without carefully considering capital cost differences. We have, therefore, dropped the capital cost variable and reestimated the model without it. These results appear as model 2 in Table 1.

The FCOST and PRODE coefficients reported as model 2 in Table 1 have the correct signs and are highly significant; the asymptotic t-statistic on the $PRODE^o$ coefficient is almost four, while the sum of the coefficients of the FCOST variables is more than four times the asymptotic standard error. The coefficients of the FCOST variables also follow the a priori lag pattern; the absolute value of the $FCOST^j$ coefficient declines as the lag increases. The technique specific dummies on gas-using alternatives are all negative and are usually highly significant as expected.

The availability problem of natural gas is certainly a major one[31]. The coefficient of the gas technique dummy is significantly more negative than the coefficients of the other multi-fuel gas specific dummies, reflecting the difficulty of obtaining non-interruptible gas service from the natural gas companies. Encouraging also is the similar order of magnitude of the total fuel cost effect ($\beta_1 \sum_{i=0}^{2} a_i = -4.8096$) and the non-fuel production expense effect ($\beta_2 b_o = -8.5299$). This indicates that the weights in the decision index are similar as would be expected, if the firm at least sought to minimize variable costs.

A further test of the conditional logit model is to apply the a priori constraint on the equality of the coefficients of multi-fuel gas technique dummies. The constrained conditional logit model appears as Model 3 in Table 1. The null hypothesis that this constraint is valid cannot be rejected at the 5% level [32,33]. It is this model that is considered appropriate for estimation purposes.

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[31]
A dummy that would allow for lower probabilities of choosing gas alternatives after 1960 as a result of F.P.C. price controls on natural gas was included in the conditional logit model. The coefficient estimate was insignificant and of the wrong sign. The effect of F.P.C. gas price controls on electric utility choice of gas using alternatives is thus unclear.

[32]
This is tested with a likelihood ratio test X^2 (2) = 1.406, while the critical X^2 at 5% is 5.992.

[33]
Note that use of a dummy for all gas using techniques (DUM-AG) implies that the total gas-only technique specific effect equals the sum of the coefficient of DUM-AG and DUM-G (= -9.6472)

V. RESPONSIVENESS OF CHOICE PROBABILITIES TO CHANGING FUEL PRICES AND THE INTRODUCTION OF A NUCLEAR POWER ALTERNATIVE :

We now use the conditional logit model that has been estimated to examine two issues of current public policy concern. The first involves the effects on electric utility fuel choice of changing fossil fuel prices. In particular, for five plants built in the last year of our sample, we examine the sensitivity of the fuel choice probabilities to changing oil prices. Second, we examine the hypothetical effects of the easy availability of nuclear power on the choice probabilities of these sample plants based on expected cost estimates of nuclear power plants that were presented during the late 1960's. We perform this second exercise both to demonstrate the use of the conditional logit specification in analyzing the effects of new alternatives,as well as to see whether the expected cost estimates of the 1960's are consistent with the levels of nuclear power plant construction that we have in fact observed since that time, based on our estimated decision index.

Before proceeding, we should point out one important feature and strength of the conditional logit model. This is the fact that the specification implies elasticities of probabilistic choice that are not constant and are also non-linear. For example, when the expected fuel costs are approximately equal and the choice probabilities are close to one another, the price elasticities are fairly high. On the other hand, when one fuel is much cheaper than the others and this alternative has a high probability of being chosen, its own price elasticity will be much lower as will its cross-price elasticity with respect to the other fuels.

In Table 2 we present calculations for the choice probabilities of the five plants built during the last year of our sample period (1965)

T A B L E 2

CHOICE PROBABILITIES AND ELASTICITIES WITH RESPECT TO EXPECTED OIL PRICES

FOR FIVE PLANTS BEGINNING OPERATION IN 1965

P L A N T \	CAPE KENNEDY Cocoa, Fla.	BRANCH HARLEE Midgeville, Ga.	COFFEN Coffen, Ill.	NEW BOSTON South Boston, Mass.	MARSHALL Tirrell, N.C
ACTUAL TECHNIQUE CHOSEN	O I L	C O A L	C O A L	O I L	C O A L
Choice Probability of Coal Technique	.515	.741	.796	.134	.781
Elasticity	4.737	.607	.038	11.444	.061
Choice Probability of Oil Technique	.273	.009	.000	.640	.000
Elasticity	-10.328	-18.348	-29.147	-4.001	-37.145
Choice Probability of Gas Technique	.000	.001	.001	.000	.000
Elasticity	4.737	.607	.038	11.444	.061
Choice Probability of Coal-Oil Technique	.125	.157	.139	.031	.179
Elasticity	4.600	.435	-.228	11.303	-.278
Choice Probability of Coal-Gas Technique	.014	.052	.064	.009	.040
Elasticity	4.737	.607	.038	11.444	.061
Choice Probability of Oil-Gas Technique	.067	.037	.000	.170	.061
Elasticity	-3.475	-9.725	-15.871	3.025	-20.220
Choice of Probability of Coal-Oil-Gas Technique	.007	.003	.000	.015	.000
Elasticity	-3.325	-9.536	-15.579	3.179	-19.848

and the elasticities of the choice probabilities with respect to expected oil prices.[34] Except for the Cape Kennedy plant, the alternative with the highest choice probability coincides with the actual alternative that was chosen . Overall, the actual alternative or best multi-fuel alternative is chosen by our model in 75% of the cases. Table 2 also presents the elasticities with respect to oil prices. Note that the Branch Harlee, Coffen and Marshall plants with high choice probabilities for coal are not particularly sensitive to changes in oil prices. In areas of the country with these kinds of fuel price characteristics we would not expect changes in oil prices to have much of an effect on the way electricity is generated. If we examine the New Boston plant, however, we see that the choice probability of the oil technique (which is the actual technique) is very sensitive to changes in oil prices. We would expect that a moderate increase in oil prices would substantially reduce the likelihood of choosing oil and increase the likelihood of choosing coal in areas of the country with these fuel cost characteristics. In fact, after the recent increase in fuel oil prices many New England utilities have attempted to switch their plants from burning oil to burning coal and construction plans for the future call for coal rather than oil burning fossil fuel plants at the present time.

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[34] For each plant the elasticities with respect to expected oil prices are calculated from the formula

$$E_i = \frac{dP_i}{d\ EOPRICE} \cdot \frac{EOPRICE}{P_i}$$

where

E_i = the elasticity of the ith technique with respect to expected oil price.

P_i = the probability of choosing technique i.

EOPRICE = expected oil price.

The expected oil price has been calculated under the assumption that $\sum_{i=0}^{2} a_i = 1$. The calculated values of the elasticities are not very sensitive to a change in this assumption, so although the assumption is crude, our elasticity estimates should be reasonably close to the true elasticities.

In Table 3 we present choice probabilities for these same five plants, but under the assumption that nuclear power was available as a base load alternative when these plants were first commissioned. We use the estimates of fuel and production costs for nuclear plants reported by MacAvoy [35] as expected for the period 1969-1972. We are essentially asking the question: "faced with a nuclear power alternative having these hypothesized expected cost characteristics, how would the choice probabilities of the various alternatives be affected? " As can be seen from the table, the nuclear power alternative dominates everything else. If the firms really expected these low costs for nuclear power virtually all new construction would have used this alternative. While a substantial number of plants commissioned since the late 1960's have been nuclear plants, the proportion has been far less than 100% in most regions of the country [36]. The utility firms apparently (and quite wisely) did not believe that nuclear power would be quite as cheap as these early optimistic estimates indicated and continued to build fossil fuel plants. In some areas of the country, like New England, where fossil fuel prices are very high, almost 100% of new base load capacity has been nuclear, however [37].

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[35] See MacAvoy [6] Appendix C. One of the interesting things about these figures is that not only were nuclear fuel costs much lower than fossil fuel costs, but the estimated construction costs were about the same for nuclear and fossil fuel capacity (which allows us to use model (3)). Experience has indicated that while the estimates of the energy costs of nuclear were not too bad, the estimates of construction costs were far too low. The cost of a kilowatt of nuclear capacity today is between 25% and 100% more expensive than comparable fossil fuel capacity (depending on the fuel burning technique).

[36] See National Economic Research Associates [11], page 28, table 12.

[37] Ibid.

CHOICE PROBABILITIES WITH A HYPOTHESIZED NUCLEAR ALTERNATIVE

P L A N T	CAPE KENNEDY	BRANCH HARLEE	COFFEN	NEW BOSTON	MARSHALL
Choice Probability of:					
C O A L	.003	.002	.009	.000	.040
O I L	.002	.000	.000	.001	.000
G A S	.000	.000	.000	.000	.000
COAL–OIL	.001	.000	.002	.000	.009
COAL–GAS	.000	.000	.001	.000	.002
OIL –GAS	.000	.000	.000	.000	.000
COAL–OIL–GAS	.000	.000	.000	.000	.000
NUCLEAR	.994	.997	.989	.999	.948

T A B L E   3

VI. CONCLUSIONS

We have attempted here to analyze the fuel choice behavior of electric utilities in the United States by giving explicit recognition to the fact that the technology for generating electricity is characterized by a small number of discrete production techniques. A particular discrete choice model -- the conditional logit model -- has been chosen as the basis for the analysis. We believe that this approach has yielded a number of interesting insights into the nature of electricity generating technology and fuel choice behavior by electric utilities.

The analysis of the real cost and technological characteristics indicated that boiler efficiencies (heat rates) have been essentially constant since 1950 and that improvements in boiler efficiency arising from scale increases above 200 MW of capacity are at best miniscule. Secular improvements in average boiler efficiency observed for the electric utility industry appear to be the result of the turnover in generator stocks rather than continuing technological improvement. In addition, the heat rate is invariant to the particular fuel chosen. Real production expenses on the other hand exhibit both productivity increases -- on the order of 4% per year -- and scale economies. In addition, the analysis indicated that non-fuel production expenses are highest for the coal burning technique, and lowest for the gas burning technique. Finally, the real capital cost of generating plants exhibit virtually no scale economies, but technological change in steam plant production is on the order of 5% per year. Coal plants exhibit the highest construction costs.

Despite complications resulting from problems in the natural gas market, the conditional logit fuel choice model also performed fairly well. Fuel cost and non-fuel production expense variables are highly significant and have the proper signs. The model "chooses" the actual

single fuel or best multi-fuel alternative in 75% of the cases. The fact
that the observed prices for natural gas do not reflect the actual
opportunity cost of natural gas supply leads to much less natural gas
being chosen than objective cost minimization would indicate. These
characteristics of the natural gas market forced us to use a technique
specific dummy variable for gas alternatives which made it difficult
to statistically identify a coefficient for the capital cost variable.
We believe that more effort must be devoted to a more complete model of
natural gas allocation procedures to electric utilities. Needless to
say this is not a trivial task.

The estimated conditional logit model was used to analyze the
effects of changing oil prices and the introduction of a hypothetical
nuclear power alternative on the choice probabilities associated with
five specific plants that went into operation in 1965. Three of these
plants faced very favorable expected coal prices and as a result even
large reductions in oil prices would have only small effects on the
probability of choosing coal as a fuel. Since many areas of the country
face fuel price configurations similar to those for these plants,
changing oil prices are not likely to affect fuel choice behavior in
any important way. This insensitivity was not characteristic of the
plant located in New England, where even relatively small increases in
oil prices would substantially reduce the probability of choosing oil
as a fuel for generating electricity. We would expect that recent in-
creases in the price of oil will dramatically decrease the likelihood
of choosing oil as an alternative for new plants in areas such as
New England.

Finally, we obtained estimates of the expected costs of nuclear
power -- an alternative that was essentially not in existence during
our sample period -- to see how its availability would affect the choice

probabilities associated with the characteristics of fossil fuel alternatives faced for five representative plants. Based on these nuclear cost expectations, the probability of choosing nuclear power approached 100%. Since except in New England and the Middle Atlantic states, new base load steam plant construction has included substantial amounts of fossil fuel capacity along with some nuclear, it appears that these early optimistic projections were (quite wisely) not taken too seriously.

All things considered, viewing the fuel choice behavior of electric utilities explicitly as a discrete choice problem has led to a number of interesting insights into both the nature of the technology and the behavior of electric utilities. We believe that this approach can be useful in analyzing similar decision problems in other industries where a continuum of decision possibilities is not a reasonable characterization of the choice alternatives. Hopefully such analysis will lead to a set of behavioral models which are both more pleasing discriptively and lead to better predictions of the effects of a changing economic environment.

A P P E N D I X

THE DATA

The data on production expenses and capital costs of seventy-three plants was found in the F.P.C. publication Steam-Electric Plant Construction Cost and Annual Production Expenses, annual supplements from 1950-1966. Statewide fuel price data for electric utilities was available in the Edison Electric Institute Statistical Yearbooks from 1951-1966. The fuel-burning technique for each plant was assumed to be the technique used in the second year of plant operation.

Utility non-fuel production expense deflators were constructed from a time series of electric company worker hourly earnings from the Bureau of Labor Statistics Employment and Earnings 1939-1972 and regional weights calculated from regional occupational wages for electric systems workers found in Table 2 of the U.S. Department of Labor's Industry Wage Survey: Electric and Gas Utilities, October-November 1967.

Capital expenditure deflators were constructed from time series in Handy-Whitman Associates' Index of Cost Trends of Electric Light and Power Construction and city construction cost indexes for 1967 in Means Building Construction Cost Data 32nd Annual Edition, published by Robert Snow Means Co. Ind. - Construction Consultants and Publishers.

The Hall-Jorgenson cost of capital measure was constructed from the formula in footnote([22]) with the following data and assumptions. The user cost of funds was assumed to be the Moody's weighted averages on newly issued domestic bonds of light, power and gas companies in that year, found in Moody's Public Utility Manual 1973. This assumption seems

warranted from Modigliani and Miller's study [10] which found that the
cost of funds to the utility industry was indeed well approximated by
the interest rate on their long term bonds. The price deflator for
capital expenditures has been described above. The replacement rate
has been calculated from the formula in Hall-Jorgenson [4]; d =2.5/L,
where L = lifetime of the plant. The lifetime of a steam-electric plant
is assumed to be 35 years, the figure used in the Draft Report January
10, 1974, an internal document of the National Energy Board, Canada,
Newfoundland Task Force on the Gulf-Island Project. The statutory tax
rate has been obtained from the Bischoff study [2], while the effective
tax credit in 1962 and 1963 for a steam-electric plant was assumed to
be around two percent which equals 3/7 (utilities were only given 3/7
of the tax credit appropriate for other industries) of the effective
tax credit used in Hall-Jorgenson multiplied by 4/5 which is the per-
centage of a steam-electric plant cost devoted to equipment and is
thus covered under the investment tax credit provisions of the Revenue
Act of 1962. The present discounted value of depreciation was calculated
using the Hall-Jorgenson formulae and assumptions of the depreciation
scheme used. The allowable tax lifetime on steam-electric plants was
assumed to equal the allowable tax lifetime on structures found in Hall-
Jorgenson.

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