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ORNL/Sub--85-7685/1-11

DE86 014410

POWER PLANT ECONOMY OF SCALE AND COST TRENDS — FURTHER ANALYSES AND REVIEW OF EMPIRICAL STUDIES

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Date Published - July 1986

Report Prepared by
Construction Resources Analysis
The University of Tennessee
Knoxville, Tennessee
under
Subcontract No. 41B-07685C-Y11

for

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGEMENT

This study was performed by Construction Resources Analysis, University of Tennessee, under contract with the Oak Ridge National Laboratory. Charles F. Fisher, Jr., Soon Paik and William R. Schriver were the principal investigators. Joyce Holloway typed the manuscript.

The study staff wishes to express their appreciation to Howard I. Bowers, manager of the Engineering Evaluation Group, Engineering Technology Division, Oak Ridge National Laboratory, for his helpful comments and suggestions during the course of this study.

The analyses and conclusions of this study are the sole responsibility of the principal investigators, based upon their best reasonable judgement, and are not necessarily endorsed by the Oak Ridge National Laboratory.

C.F.F.
S.P.
W.R.S.

ABSTRACT

Multiple regression analyses were performed on capital cost data for nuclear and coal-fired power plants in an extension of an earlier study which indicated that nuclear units completed prior to the accident at Three-Mile Island (TMI) have no economy of scale, and that units completed after that event have a weak economy of scale (scaling exponent of about 0.81). The earlier study also indicated that the scaling exponent for coal-fired units is about 0.92, compared with conceptual models which project scaling exponents in a range from about 0.5 to 0.9. Other empirical studies have indicated poor economy of scale, but a large range of cost-size scaling exponents has been reported.

In the present study, the results for nuclear units indicate a scaling exponent of about 0.94 (without statistical significance) but with no economy of scale for large units, that a first unit costs 17% more than a second unit, that a unit in the South costs 20% less than others, that a unit completed after TMI costs 33% more than one completed before TMI, and that costs (in constant dollars) are increasing at 9.3% per year.

In the present study, the results for coal-fired units indicate a scaling exponent of 0.93 but with better scaling economy in the larger units, that a first unit costs 38.5% more, a unit in the South costs 10% less, flue-gas desulfurization units cost 23% more, and that costs (in constant dollars) are increasing at 4% per year.

Comparisons with regression models of other studies indicate that additive models are not appropriate to support calculated scaling exponents in the 0.25 to 0.60 range, and suggest that the lowest valid scaling exponents from multiplicative models are about 0.6 after multicollinearity and simultaneity bias problems are accounted for.

SUMMARY

The Construction Resources Analysis (CRA) office at the University of Tennessee has conducted a study, funded by the Oak Ridge National Laboratory, to build upon and extend the results of an earlier CRA multiple-regression analysis of power plant construction costs. The earlier study, sponsored by the Edison Electric Institute (EEI), raised some important questions pertaining to the economy of scale of both nuclear and coal-fired power plants, and to the effect of the accident at Three-Mile Island (TMI) on nuclear power plant costs and economy of scale.

The earlier CRA-EEI regression analysis indicated that nuclear units completed prior to TMI have no economy of scale, and that units completed (or nearing completion) after TMI have a weak economy of scale. It also indicated that the economy of scale for coal-fired, steam-electric generating units is significantly less than the economy of scale projected in most conceptual or engineering cost models, which project scaling exponents in a range from about 0.5 to 0.9.

Several other analyses of historical cost data for power plant construction have also indicated a weak economy of scale, although there is broad variance in estimates of these scaling exponents, which range generally from about 0.5 to 1.0 for nuclear units and for coal-fired units.

The primary purposes of this study were to build upon and extend the results of the earlier CRA analysis and to investigate the differences in models used in the various regression analyses to determine if the variance in estimates of scaling exponents is partly attributable to these differences. An additional facet of the study was a further investigation of the cost time trend, particularly with respect to coal-fired units with and without flue-gas desulfurization (FGD) and nuclear units completed before and after TMI.

The CRA-EEI data base, consisting of capital investment costs (including interest during construction) of 108 coal-fired units and 89 nuclear light water reactor units, was subjected to multiple-regression analyses with various model specifications approximating models used in seven analyses reported in the literature. Some additional analyses were performed on costs excluding interest during construction (IDC). Because of incomplete information on some units, the sample consisted of only 94

coal-fired units and only 31 nuclear units. Regressions on the coal-fired units resulted in greater variance than the variance in the regressions for total costs, and the regressions for nuclear units also produced a large variance compared with the variance in the regressions for total cost. Regressions were also carried out by six direct and indirect sub-accounts, but the even smaller sample sizes and larger variance produced widely variable results that were not considered to be reliable.

Regressions using a basic multiplicative model, a model in which cost as the dependent variable is expressed as a product of independent variables (with the natural logarithm of cost per kilowatt becoming the dependent variable in the transformed equation used as the linear regression equation) were carried out for the coal-fired units and for the nuclear units. The year of construction start and the natural logarithm of capacity were used as the only continuous independent variables, and dummy variables for first units and for units in the South were used for both data sets. In addition, a dummy variable for FGD was used in regressions for coal-fired units to estimate the cost increase factor for units with FGD, and a dummy variable for TMI was used for nuclear units to estimate a cost factor for units completed after TMI.

The results for nuclear units indicate a scaling exponent of about 0.94, without statistical significance, that a first unit costs 17% more than a second unit, that a unit in the South costs 20% less than others, that a unit completed after TMI costs 33% more than one completed before TMI, and that costs (in constant dollars) are increasing at 9.3% per year.

For coal-fired units, the results indicate a scaling exponent of 0.93 with less than marginal statistical significance, that a first unit costs 38.5% more, a unit in the South costs 10% less, FGD units cost 23% more, and that costs (in constant dollars) are increasing at 4% per year.

A linear (or additive) model, where cost (rather than the logarithm of cost) as the dependent variable is expressed as a sum of terms containing the variables identified above, was used to provide a comparison with the basic model referred to above. Costs were calculated from the regression equation and scaling exponents were calculated in various regions of the data set, and a large range of values for the scaling exponent was obtained. While this model may have some limited use in determining scaling exponent values in some very narrow range (with uncertain identification) near the mid-range of the data, it does not appear to be particularly suitable in determining scaling exponents or a cost trend with time.

Interactive models, which have the capability of providing much more detailed information than more basic models, were used in regression analyses which were particularly aimed at determining scaling exponents and the time trend of costs as functions of time (year of construction start) and capacity. The statistical significance was marginal in these results, although a consistent pattern was discernible.

For nuclear units, the results indicate no economy of scale for large units but increasing economy of scale with decreasing capacity values, and with economy of scale increasing rapidly with time. The results indicate that annual percent changes in cost (in constant dollars) are algebraically decreasing with time and decreasing with increasing capacity.

For coal-fired units, the results from models with interactive variables indicate that economy of scale increases with size and is little affected by time. The results also indicate that annual percent changes in cost (in constant dollars) are algebraically increasing with time.

Although the patterns seen in these models with interactive variables may be real, the range of values is so great that it appears that perhaps a multicollinearity problem and general variance in the data cause distortion in the results, making the numerical values questionable at best.

The specification of the time variable as the date of start of construction, the date of construction completion, or an intermediate value was investigated. Although the selection among these choices alters the results, the statistical significance of the regressions with these three different time specifications does not indicate that either of the later times has as much significance as the date of start of construction.

Models which include duration (or some variation) of construction were investigated, and possible simultaneity bias problems were identified. It was shown that duration added as an additional explanatory variable in a multiple-regression analysis can produce erroneous results. Additionally, it was shown that estimates of duration as a function of the independent variables may be substituted into such an equation to determine the same scaling exponent that would be obtained from a regression in which duration (or other variable creating simultaneity bias) is not included.

An examination of regression analyses reported in the literature suggests that possible simultaneity bias and/or multicollinearity problems that may exist in some multiplicative models bring into question the validity of the interpretations by some reviewers that these analyses imply a scaling exponent as low as 0.49. It is suggested that further analyses might lead to an interpretation that would indicate a less favorable scaling exponent. Discounting even lower (more favorable) values of scaling exponents calculated from additive models, this implicitly suggests that none of the power plant cost regression analyses reported in the literature indicate a verifiable scaling exponent below about 0.6 for either nuclear units or coal-fired units.

Cross-sectional analyses were used to reduce any possible multicollinearity problem in the regression equation by removing time as an explanatory variable. The values of scaling exponents for each time segment of the data agreed rather closely with the value calculated by regression for the composite data set for coal-fired units. A tendency toward improved economy of scale with larger unit sizes was observed in these analyses of time segments of the data, but the statistical significance was less than marginal.

For nuclear units, the values of scaling exponents by time segment varied considerably, and did not provide a basis to reject the hypothesis that there is no significant economy of scale for nuclear units.

The data were partitioned by capacity ranges, and regressions on each segment suggest again the economy of scale is greater for the larger sizes of coal-fired units, but a very large and unrealistic range (0.00 to 1.05) of values resulted from these regressions.

Partitioned data for nuclear units again indicate better economy of scale for small size units, but the range (0.63 to 3.49) of estimated scaling exponents for this data set also is very large and unrealistic.

The data for coal-fired units were partitioned into a set containing units with FGD and a set containing units without FGD. The regression analysis for the units with FGD indicates a scaling exponent of 0.87, which was marginally significant, compared with 0.93 for the analysis for the entire data set. The regression for the data set of units without FGD indicates a scaling exponent of 0.94, which is essentially the same as the value for the pooled data set.

LIST OF VARIABLES

Dependent Variables

C = total cost of an electric generating unit in 1984 dollars (including Interest During Construction)

DUR = duration of construction in months

LC84KW = ln C/KW

LC84KWD = LC84KW adjusted for effects of year of construction start, South or non-South location, first or add-on unit, presence of FGD (for coal-fired units) and construction completion after the Three Mile Island event (for nuclear units)

LCI84KW = LC84KW excluding Interest During Construction

LDUR = natural logarithm of construction duration in months

ln C = natural logarithm of C

ln COST = natural logarithm of the total cost of an electric generating unit in 1984 dollars (including Interest During Construction)

ln C/KW = natural logarithm of cost per kW of an electric generating unit in 1984 dollars (including Interest During Construction)

Independent Variables

CAP = net capacity of the unit in MW

D_i = DUM_i

DFGD = FGD

DUM_i = dummy variables representing years of construction start

E79 = a dummy variable set at one for nuclear units with construction completed after the TMI accident (1979 or after) and zero otherwise

FGD = a dummy variable set at 1 for coal-fired units with flue-gas-desulfurization and zero otherwise

ETIME = estimated time from announcement of a project to anticipated date of operation

FIRST = a dummy variable set at one for first units or add-on units and zero for planned, subsequent units = UNIT NO

LD60	=	natural logarithm of construction duration divided by 60
LD100	=	natural logarithm of construction duration divided by 100
LETIME	=	natural logarithm of estimated time from announcement of a project to anticipated dat of operation
LMW	=	ln CAP
ln CAP	=	natural logarithm of CAP
LUTIME	=	natural logarithm of the difference between the actual and anticipated time of operation
REG	=	SOUTH
RLDUR	=	residual of LDUR
SOUTH	=	a dummy variable set at one for units located in the South (see Figure A2, Appendix A) and zero otherwise
T	=	Time
T65	=	year of construction start minus 1965
T67	=	mid-point year between construction start and construction end minus 1967;
T70	=	year of construction end minus 1970
TMI	=	E79
UNIT NO	=	a dummy variable set at one for first units or add-on units and zero for planned, subsequent units;
UTIME	=	difference between the actual and anticipated time of operation

1. INTRODUCTION

A multiple-regression analysis of power plant construction costs (1)* was recently completed by the Construction Resources Analysis (CRA) office at the University of Tennesssee under the sponsorship of the Edison Electric Institute (EEI). This analysis raised some important questions pertaining to the economy of scale of both nuclear and coal-fired power plants, and to the effects of the accident at Three-Mile Island (TMI) on nuclear power plant costs and economy of scale.

The earlier CRA-EEI analysis indicated that nuclear units completed prior to TMI have no economy of scale, and that units completed (or nearing completion) since TMI have a weak economy of scale. The regression analysis also indicated a weak economy of scale for coal-fired plants.

Several other multiple-regression analyses have also indicated a weak economy of scale for power plant construction, although there is broad variance in estimates of scaling exponents reported in other studies of construction costs of both coal-fired and nuclear power plants.

The purposes of this study are to build upon and extend the results of the earlier CRA analysis, and to attempt to explain the variance in the estimated scaling factors reported in other studies.

The conventional method of evaluating the economy of scale in power plant construction is based upon the assumption that the capital investment cost for a unit is proportional to the unit capacity raised to a power P -- the scaling exponent. A scaling exponent less than unity indicates that an increase in scale (capacity or size) by a given factor results in a cost increase by a smaller factor, and that there is economy of scale.

Ideally, true scale economies could only be determined by comparing the costs of construction of similar generating units, differing only in capacity, built by the same contractor for the same owner at the same time on the same site. Since these data do not exist, to estimate a scaling factor it is necessary to compare costs of disparate units of differing

*Numbers in parentheses refer to similarly numbered references at the end of this report.

capacities, using multiple regression to control on the effects of different geographical locations, time period, first or add-on unit, and flue-gas desulfurization (FGD) for coal-fired units.

The relationship between cost and the independent variables, including unit capacity, may be specified in linear, logarithmic, linear-logarithmic combination, or other forms, depending upon the assumptions of the investigator. One important objective of this study is to show that much of the variance in the estimates of scale economies reported in various empirical studies may be attributed to the different model specifications, and definitions of variables.

The approach to accomplishing the objectives of this study involves: reviewing empirical studies which included estimates of scaling exponents, or from which scaling exponents could be calculated; using these various econometric models to estimate scaling exponents from the CRA-EEI power plant cost data base; specifying additional models to estimate scaling exponents from the CRA-EEI data base; and finally, comparing and assessing the results based upon the differing assumptions embedded in the various model specifications. Also investigated was the time trend of costs, particularly with respect to coal-fired units with and without FGD and nuclear units completed before and after TMI.

2. THE DATA BASE

The analyses contained in this report are based upon the CRA-EEI power plant cost data base. It consists of total investment cost (and disaggregated costs by six direct and four indirect subaccounts) for 108 fossil steam-electric units and 89 light water reactor units. (Although not used in this study, this data base also includes capital and maintenance expenditures for 491 commercially operating fossil steam electric units at 165 generating stations and is currently being expanded to include these data for commercially operating LWR units.)

A description of the powerplant investment cost data base is shown in Tables 2.1.1 and 2.1.2. These data were collected in two survey panels, one conducted in 1981 and the other in 1984.

The raw data collected from the utilities were in mixed current dollars but were converted into 1984 constant dollars by the procedure described in Appendix A. This appendix also includes the form used to collect the cost data in the second survey panel; a different form was used in the first panel. Most of the analyses reported in this study were based upon capital investment cost, including interest during construction (IDC), but some analyses, where noted, were also performed with IDC excluded.

Since this study is based upon an examination of various model specifications to estimate scale economy and time trends using the CRA-EEI data base, it may be helpful to the reader to show plots of the data at this point. Each of the plots reinforces the general observation that there is a large amount of variance in the data, and it will be shown in the succeeding analyses that this variance places severe limitations on statistical precision.

The data in the plots have been treated for the effects of the independent variables specified in Equations (3.1.11) and (3.1.12), net of the variable shown on the x-axis, i.e., log of unit capacity (ln CAP) or time of construction start. This procedure was followed so that other factors could be held constant, making any scale economy or time effects more readily observable. The data presented here include IDC, but similar plots excluding IDC appear in Appendix B.

TABLE 2.1.1.

SELECTED SUMMARY CHARACTERISTICS OF RECENTLY COMPLETED FOSSIL STEAM-ELECTRIC UNITS

CHARACTERSITICS OF POWERPLANT	CATEGORY	TOTAL MEGAWATT	NUMBER OF UNITS	AVG CAPACITY MEGAWATT	AVG DURATION MONTHS	AVG IDC COST PERCENT
TOTAL SAMPLE		61731	120	514	60.3	14.6
CAPACITY(MW)	000<=CAP<300	4429	20	221	50.0	12.5
	300<=CAP<500	14710	35	420	53.1	14.4
	500<=CAP<700	27094	45	602	67.5	15.7
	700<=CAP	15498	20	775	67.0	14.7
COAL / FGD		24734	51	485	59.9	15.6
OIL AND GAS		1490	5	298	64.5	13.5
CONSTR START	1970	284	1	284	—	—
	1971	1160	2	580	67.0	12.9
	1973	3246	5	649	114.2	18.4
	1974	9027	15	602	66.5	11.9
	1975	5868	14	419	58.2	15.9
	1976	4609	9	512	61.9	12.9
	1977	9174	16	573	59.4	12.8
	1978	12000	24	500	50.7	13.8
	1979	8832	18	491	57.1	18.3
	1980	3726	10	373	45.8	15.2
	1981	3805	6	634	67.3	15.1
CRA REGION	REG1	2441	5	488	73.5	18.4
	REG2	14551	26	560	66.2	15.8
	REG3	10331	19	544	63.4	13.9
	REG4	9069	19	477	60.0	12.6
	REG5	17309	33	525	56.1	15.5
	REG6	4883	10	488	51.7	10.9
	REG7	2717	6	453	51.1	16.8
	REG8	430	2	215	63.5	8.7

TABLE 2.1.2.

SELECTED SUMMARY CHARACTERISTICS OF RECENTLY COMPLETED AND CONSTRUCTION-IN-PROGRESS NUCLEAR UNITS

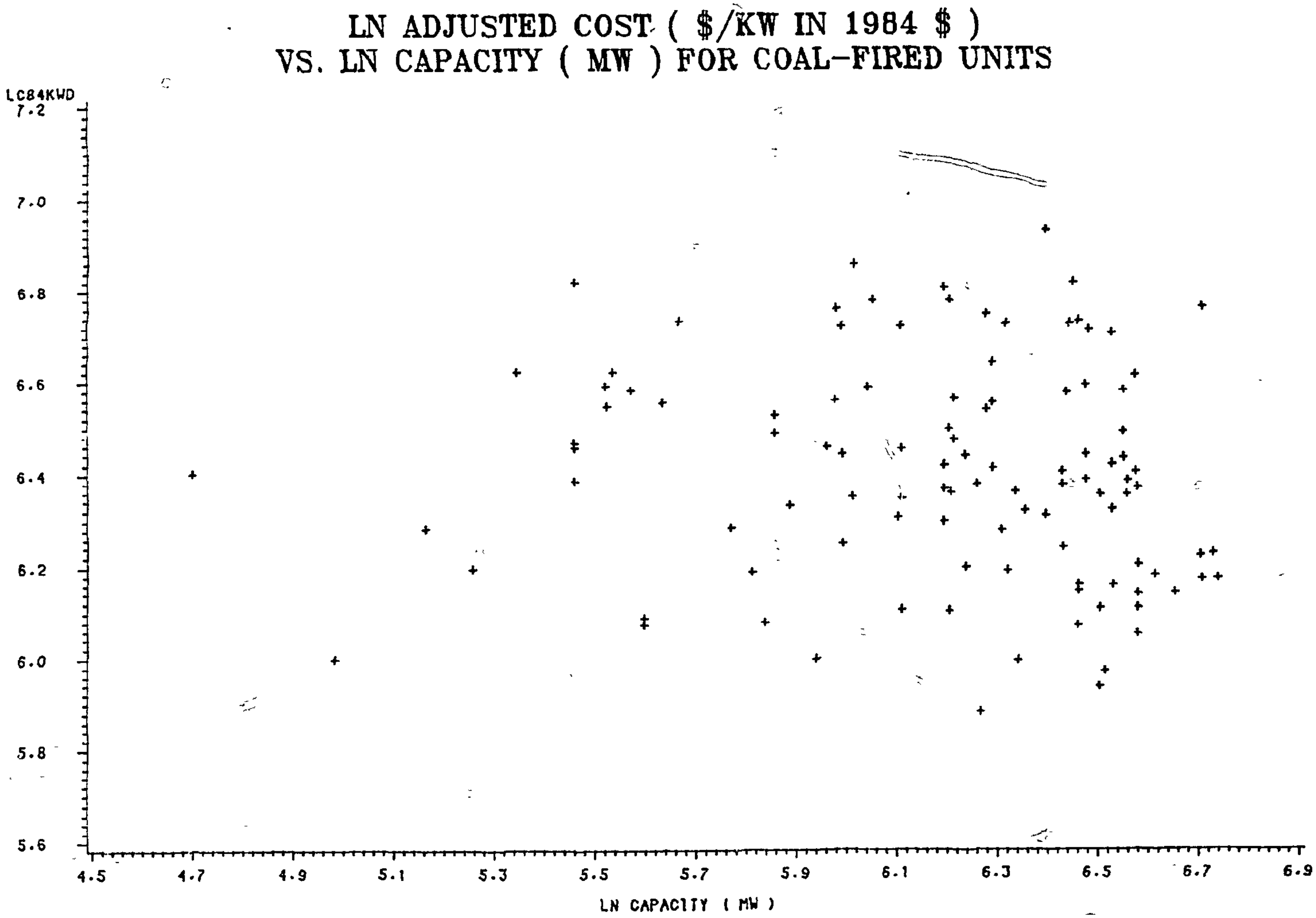
CHARACTERISTICS OF POWERPLANT	CATEGORY	TOTAL MEGAWATT	NUMBER OF UNITS	AVG CAPACITY MEGAWATT	AVG DURATION MONTHS	AVG IDC COST PERCENT
TOTAL SAMPLE		91383	95	962	99.9	30.5
CAPACITY(MW)	CAP< 1000	36189	46	787	75.3	21.6
	CAP>=1000	55194	49	1126	123.0	31.3
CONSTR START	1967	9626	11	875	69.3	.
	1968	16894	20	845	84.3	25.4
	1969	6501	7	929	79.7	.
	1970	8887	10	889	81.0	.
	1971	3850	4	963	81.0	.
	1972	10164	11	924	120.3	30.0
	1973	8280	8	1035	125.2	25.9
	1974	12595	11	1145	146.6	31.8
	1975	4480	4	1120	118.0	34.5
	1976	8022	7	1146	109.6	33.4
	1977	2084	2	1042	87.0	.
CRA REGION	REG1	18242	20	912	91.6	32.9
	REG2	9449	10	945	118.2	27.7
	REG3	31890	33	966	101.1	30.9
	REG4	11969	13	921	90.0	31.4
	REG5	9910	9	1101	107.7	29.1
	REG6	2385	3	795	73.9	.
	REG7	2230	2	1115	97.5	21.8
	REG8	5308	5	1062	117.0	28.9

Figures 2.1.1 and 2.1.2 show plots of the log of cost (in constant 1984 dollars) per kW of capacity (ln (C/KW)) versus ln CAP for coal and nuclear units, respectively.

Figures 2.1.3 and 2.1.4 show ln (C/KW) versus time of construction start for the same coal and nuclear units, respectively.

The succeeding analyses will be devoted to attempting to unravel whatever patterns that may exist in these data, recognizing that the substantial variance observable in the plots will, in most instances, deny strong and precise statistical statements.

Figure 2.1.1.



LN ADJUSTED COST ($/KW IN 1984 $)
VS. LN CAPACITY (MW) FOR COAL-FIRED UNITS
LC84KWD
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
4.5
4.7
4.9
5.1
5.3
5.5
5.7
5.9
6.1
6.3
6.5
6.7
6.9
LN CAPACITY (MW)

Figure 2.1.2.

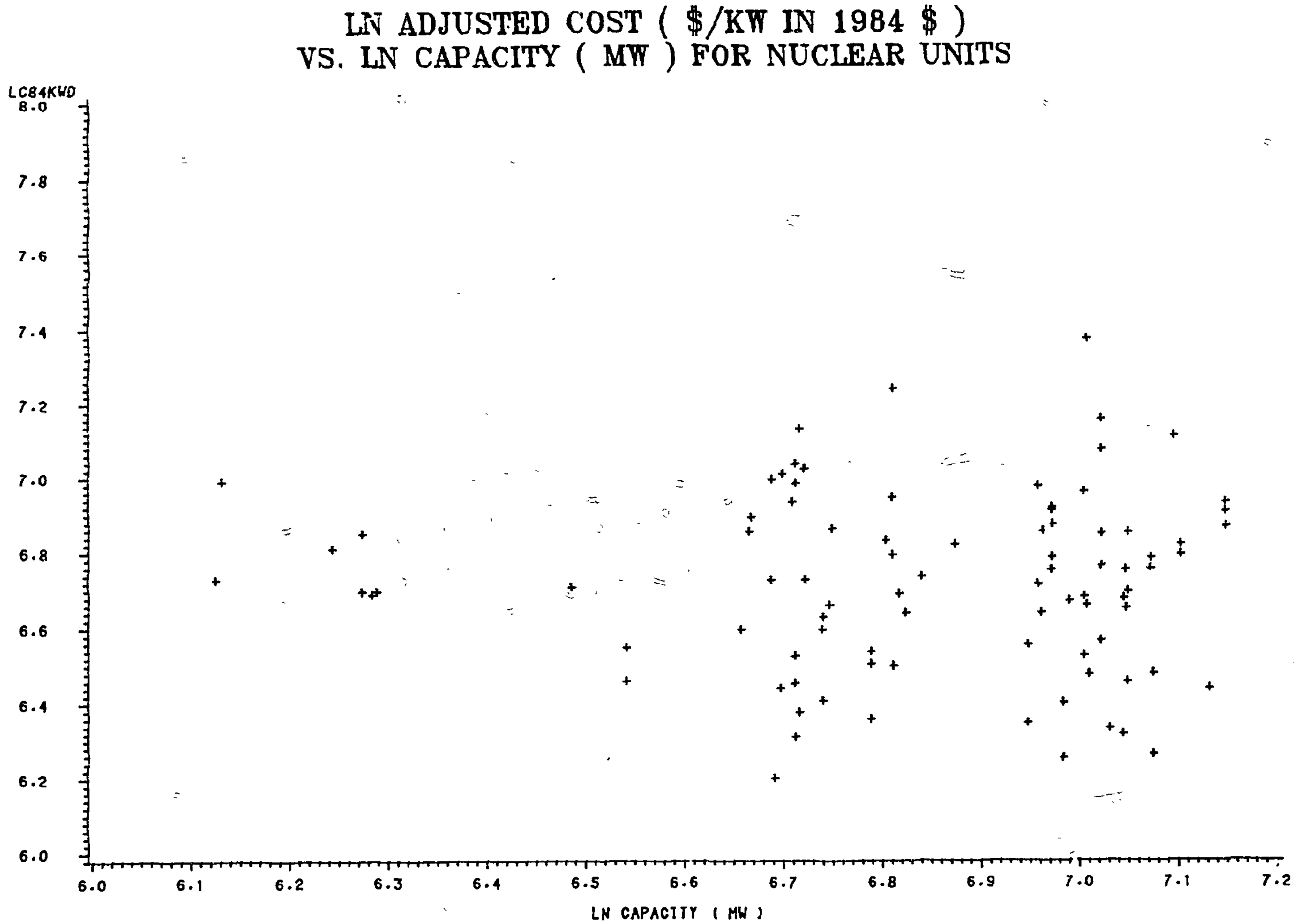

LN ADJUSTED COST ($/KW IN 1984 $)
VS. LN CAPACITY (MW) FOR NUCLEAR UNITS
LC84KWD
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
6.0
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7.0
7.1
7.2
LN CAPACITY (MW)

Figure 2.1.3.

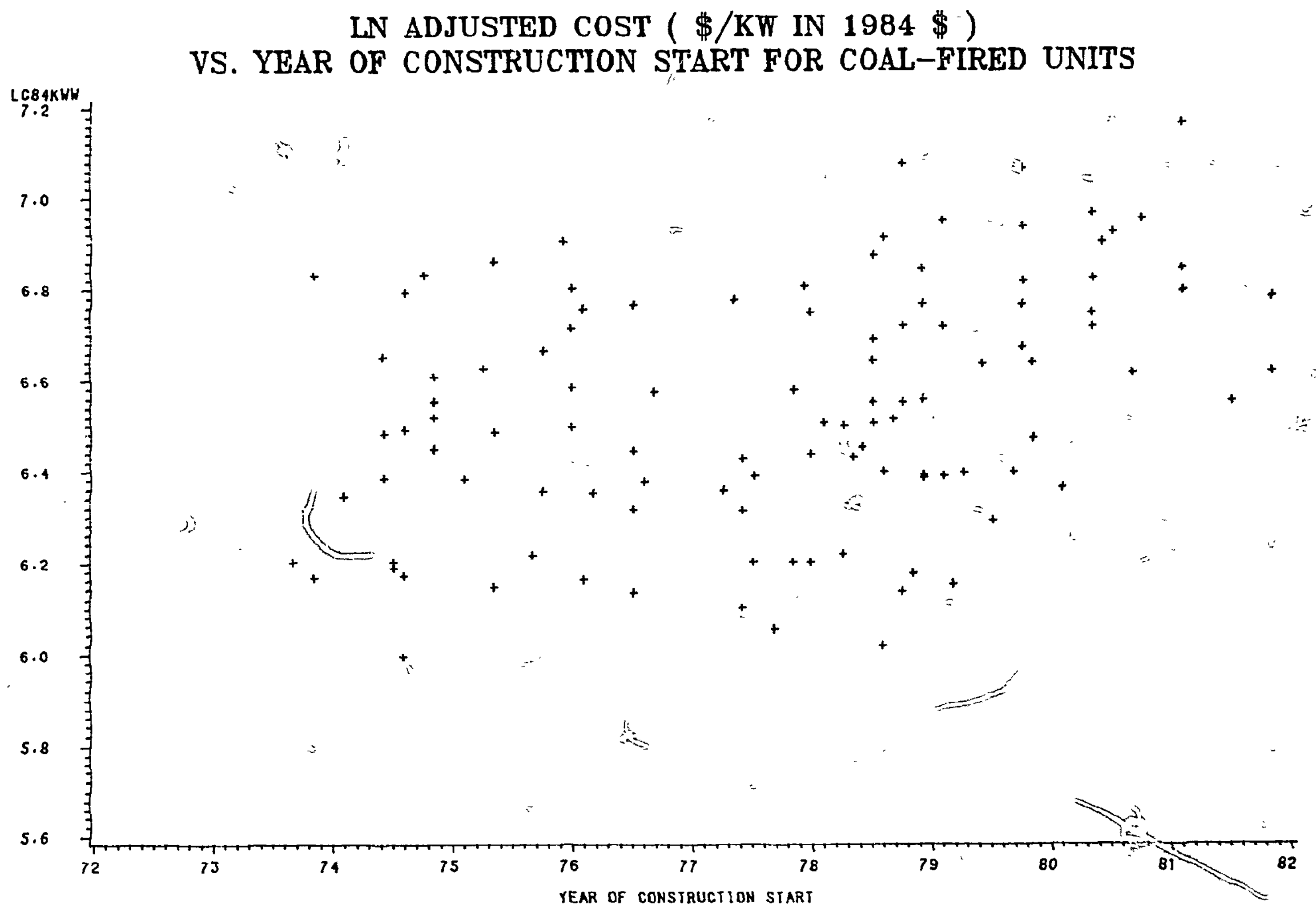
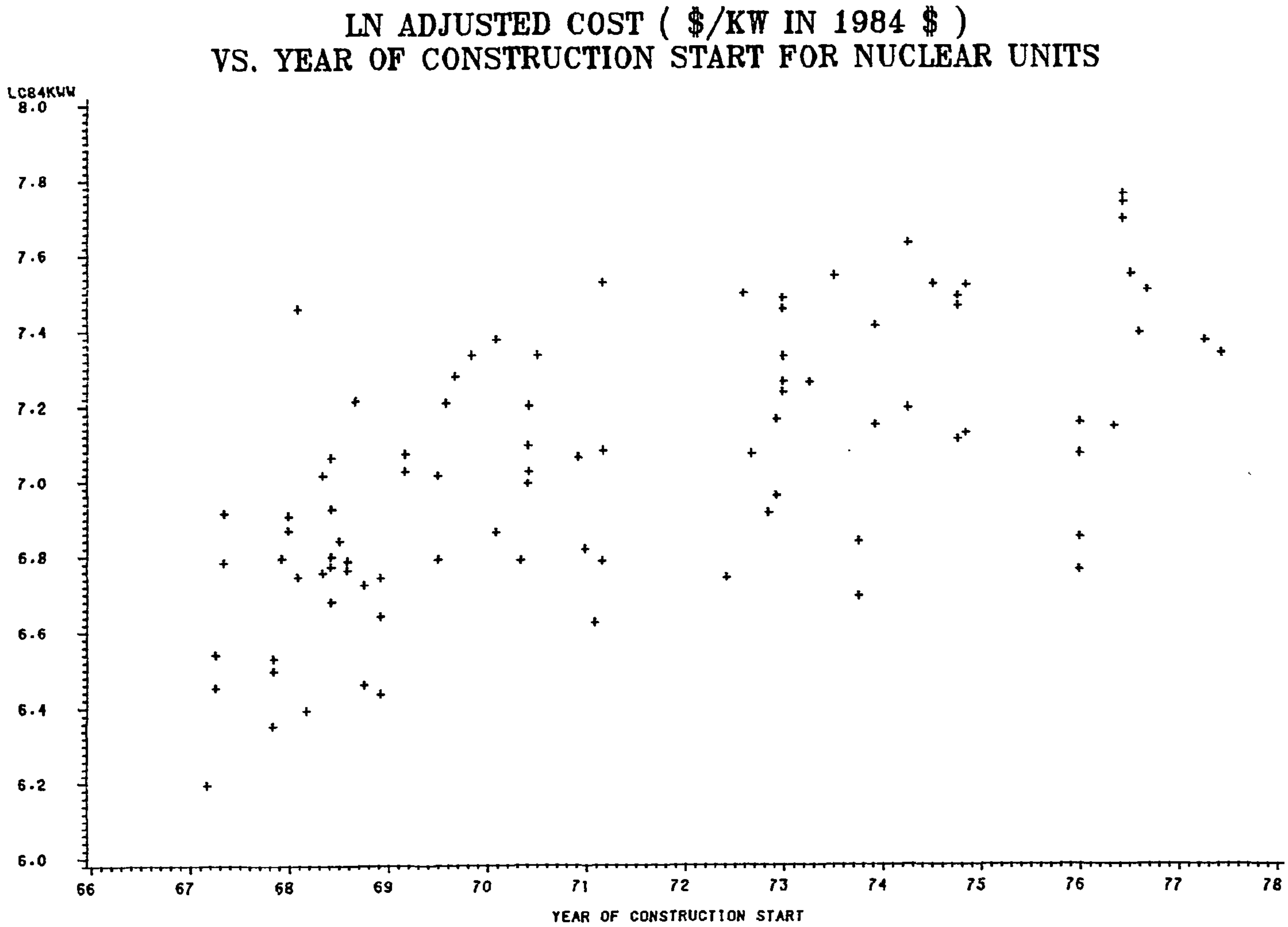

LN ADJUSTED COST ($/KW IN 1984 $)
VS. YEAR OF CONSTRUCTION START FOR COAL-FIRED UNITS
LC84KWW
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
72
73
74
75
76
77
78
79
80
81
82
YEAR OF CONSTRUCTION START

Figure 2.1.4.


LN ADJUSTED COST ($/KW IN 1984 $)
VS. YEAR OF CONSTRUCTION START FOR NUCLEAR UNITS
LC84KWW
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
66
67
68
69
70
71
72
73
74
75
76
77
78
YEAR OF CONSTRUCTION START

3. ANALYSIS

3.1 MODEL SPECIFICATION

The classical cost-size scaling relationship is based on the simplifying assumption that the capital investment cost is proportional to the size raised to a power P -- the scaling exponent.

For steam-electric generating units, the appropriate size term is the electrical generating capacity, and the corresponding expression for the ratio of the costs of two units A and B is of the form

$$\frac{\text{Cost of unit A in \$}}{\text{Cost of Unit B in \$}} = \left(\frac{\text{Size of unit A in MW(e)}}{\text{Size of unit B in MW(e)}}\right)^{P} \qquad (3.1.1)$$

A value of P, the scaling exponent, equal to one indicates the cost is directly proportional to size, and there is no economy of scale. Economy of scale results from scaling exponent values less than one so that if the size is doubled, for example, the cost goes up by a factor less than two.

An alternate form of Eq. 3.1.1 frequently used is obtained by dividing the numerator on each side of the equation by the size of unit A and dividing the denominator on each side of the equation by the size of unit B. The resulting equation may be expressed as the ratio of cost per kilowatt for the different size units as follows:

$$\frac{\text{Cost of unit A in \$/kW(e)}}{\text{Cost of unit B in \$/kW(e)}} = \left(\frac{\text{Size of unit A in MW(e)}}{\text{Size of unit B in MW(e)}}\right)^{P-1} \qquad (3.1.2)$$

Thus, when there is economy of scale (P less than one), the exponent in Eq. 3.1.2 is negative, and $P-1 = 0$ when the total cost of a unit increases in direct proportion to the size of the unit.

In the multiple-regression analyses of power plant costs reported in the literature, both an additive model and a multiplicative model are used. An additive model may be of the form

$$\text{COST} = A_o + A_1(X_1) + A_2(X_2) + \ldots \qquad (3.1.3)$$

where the values of A_i are regression coefficients and the values of X_i are variables representing selected characteristics of the unit (capacity, location, etc.) as explanatory variables, plus time (usually) as an additional explanatory variable. One of the variables is usually the capacity raised to a power q, although a value of q equal to one has been used in the additive models found in the literature.

Time (year of construction start, for example) has no inherent effect on cost, but factors contributing to cost changes (which can generally be either positive or negative) become applicable at points along the time scale, and time serves as a convenient substitute for the initial appearance of these factors, the impacts of which may tend to accumulate as some fairly smooth function of time. Other factors may result in identifiable and abrupt step functions. An example is the accident at Three-Mile Island and its impact on costs of nuclear units, as well as licensing time, construction time, cubic yards of concrete for a nuclear unit, etc. The magnitude of the impact of these factors may be sufficient to warrant the inclusion of a step function as a dummy variable to divide the time trend into two segments, each of which is presumably a fairly smooth function with relatively small variance about the mean compared with the variance for a single continuous function, to estimate the equation.

The multiplicative model is based on the assumption that the cost is proportional to the capacity raised to the power P

$$\text{COST} = F(\text{CAP})^P \qquad (3.1.4)$$

where F is a multiplying factor. The multiplying factor F may be different for plants with different characteristics (a first unit, a location in the South, a specific year of construction start, etc.) and may itself be the product of several factors, F_1, F_2, F_3, etc. The resulting multiplicative model may be expressed as

$$\text{COST} = F_1(F_2) \ . \ . \ . \ (F_n)(\text{CAP})^P, \qquad (3.1.5)$$

and this can be reduced to a linear model by taking the logarithm of both sides of the equation. This results in the linear equation

$$\ln \text{COST} = \ln F_1 + \ln F_2 + . \ . \ . + \ln F_n + P(\ln \text{CAP}) \qquad (3.1.6)$$

This can be transformed into a suitable equation for linear regression analysis if each of the ($\ln F_i$) terms is defined as $a_i X_i$, so that

$$F_i = e^{(a_i X_i)} \tag{3.1.7}$$

Selection of the variables, X_i, is similar to the selection for the additive model, although the appropriate mathematical form may be different, e.g., the logarithm of a variable or the cosine of the variable, etc.

With the above substitution, the form of the equation for multiple-regression analysis becomes

$$\ln COST = a_o + a_1X_1 + a_2X_2 + . . . + P(\ln CAP) \tag{3.1.8}$$

with a_o (as the intercept) and the coefficients a_i and the coefficient P determined by the regression.

The multiplicative model was selected as the basic equation for the multiple-regression analyses of the CRA-EEI data base, although comparisons are made with the additive model in the following section, and the only two continuous variables are capacity (as ln CAP) and time (year of construction start). Other variables are dummy variables, which have a value of either zero or one, depending on the applicability of the dummy variable to a unit in the data set. For example, a dummy variable for a first unit takes on a value of zero for a second (or subsequent) unit at a location where the second (or subsequent) unit was planned along with a prior unit constructed on the site with construction initiated on the prior unit within two years of the beginning of construction of the subsequent unit. This planned sequence is assumed to allow for some common engineering costs and mobilization of a construction force, as well as some common facilities. For a first unit, or one constructed at a plant with existing units but with several intervening years between construction of units (where the advantage of common engineering and planning is assumed absent, and where there is assumed to be relatively little savings resulting from sharing of facilities), the dummy variable takes on a value of one, and a multiplying factor for a first unit results from the corresponding regression coefficient.

Other dummy variables used are for the region (set at 1 for units in the South and 0 otherwise), FGD (set at 1 for units with FGD and 0 for others) for coal-fired units, and TMI (set at 1 for units completed after TMI and 0 otherwise).

The time variable selected for the basic model in the analyses in subsequent sections is the year of construction start. This is thought by some to best characterize a unit by the existing state of the art in the design phase of the unit, and to reflect the regulatory and macroeconomic environment applicable to the unit. Others feel that the date of commercial operation better reflects the cost requirements, and others opt for the mid-point of construction as a compromise. The latter options may result in decreased variance in the data, as time related costs (escalation) tend to make the plants which are completed within the same time frame have costs which are comparable.

Some comparisons and further discussions of the use of the three aforementioned time options are presented in the following sections.

The mathematical form for the time variable in the basic model for the analyses of the CRA-EEI data is the linear form. This has an advantage over the logarithm of time (year of construction start) in that the results do not depend on the base year selected for the time measurement.

The time trend parameter of primary interest is the annual percent change in construction cost, which is 100 times the fractional change in cost. The fractional change in cost is the reciprocal of cost multiplied times the partial derivative of cost with respect to time. This product is the partial derivative of ln (cost) with respect to time. Thus, when time is used linearly as the time variable in the regression equation, the regression coefficient of time represents the annual fractional change in cost when time is used only to the first power as a variable. (Discussions of time squared as an additional variable are presented in Section 3.3). Thus, selection of the linear form of time constrains the results to indicate a constant value of the annual percent change in cost.

The choice of the logarithm of time in a linear regression model imposes a more objectionable constraint on the time trend indicated by the regression results. For ln (time) as the independent time variable, the partial derivative of ln (cost) with respect to time results in a term which is the regression coefficient of ln (time) divided by time. Thus, the regression results would indicate that the absolute value of the annual percent change in cost decreases with time. Results of analyses presented in Section 3.3 indicate that, of these two choices, the linear function of time is the prudent choice for the CRA-EEI data being analyzed in this report.

With these variables thus established, the basic multiple-regression model (with regression coefficients to be determined) for nuclear units is of the form

$$\ln \text{COST} = a_o + a_1 T + a_2(\ln \text{CAP}) + a_3(\text{UNIT NO}) + a_4(\text{REG}) + a_5(\text{TMI}). \tag{3.1.9}$$

In this equation, T is a year representing the vintage of the unit minus a reference year, CAP is the unit capacity (in megawatts), UNIT NO is a dummy variable which has a value of one for a first unit and zero otherwise, REG is a dummy variable which has a value of one for a unit located in the South (Region III and V) and zero otherwise, and TMI is a dummy variable (designated as E79 in the computer programs) which has a value of one for nuclear units completed after TMI and zero otherwise.

For coal-fired units, the corresponding equation is

$$\ln \text{COST} = b_o + b_1(T) + b_2(\ln \text{CAP}) + b_3(\text{UNIT NO}) + b_4(\text{REG}) + b_5(\text{FGD}), \tag{3.1.10}$$

where, in addition to dummy variables defined above, FGD is a dummy variable which has a value of one for coal-fired units with FGD and zero otherwise.

Alternate forms of these equations give the cost per unit of capacity as the dependent variable, and are obtained by noting that the logarithm of (COST/CAPACITY) is equal to ln COST minus ln CAP, and subtracting ln CAP from each side of the equation. With C/KW as the notation for cost per unit of capacity, the multiple-regression model for nuclear units is

$$\ln C/KW = a_o + a_1(T) + a_2(\ln CAP) - \ln CAP$$
$$+ a_3(UNIT\ NO) + a_4(REG) + a_5(TMI)$$
$$= a_o + a_1(T) + (a_2 - 1)(\ln CAP) + a_3(UNIT\ NO)$$
$$+ a_4(REG) + a_5(TMI). \qquad (3.1.11)$$

The coefficient $(a_2 - 1)$ is to be determined by regression and corresponds to $(P - 1)$, which is the scaling exponent minus one.

The corresponding equation for coal-fired units is

$$\ln C/KW = b_o + b_1(T) + (b_2 - 1)(\ln CAP) + b_3(UNIT\ NO)$$
$$+ b_4(REG) + b_5(FGD). \qquad (3.1.12)$$

The total cost equations give the cost (in dollars) divided by one thousand when capacity, in megawatts (MW), is used. The unit cost equations give the cost in dollars per kilowatt (kW) when capacity, in megawatts, is used.

Power plant investment cost analyses found in the literature are about equally divided in the selection of total cost (C) or cost per kW (C/KW) of capacity as the dependent variable. Either specification is appropriate for the multiplicative model, but the reader should be cautioned about the interpretation of the statistical significance associated with the capacity variable in the two forms.

In the total cost equation, the coefficient of (ln CAP) should be tested to determine whether its distribution includes the interval of the value of <u>one</u> (implying no economy of scale). In the C/KW equation, the coefficient of (ln CAP) should be tested to determine whether its distribution includes the interval of the value of <u>zero</u> (implying no economy of scale).

Consider, for example:

$$\ln C = d\ (\ln CAP) + K \qquad (3.1.13)$$

$$\ln C/KW = f\ (\ln CAP) + K, \qquad (3.1.14)$$

where f = (d - 1). The coefficient d in the linear equation for (ln C) represents the scaling exponent, and f in the linear equation for (ln C/KW) represents the scaling exponent minus one. An example illustration of the appropriate statistical significance test of the two coefficients is as follows:

$$\ln C = 0.9(\ln CAP) + K \; . \; . \; . \; CAP_{s.e.} = 0.3 \qquad (3.1.15)$$

$$\ln C/KW = -0.1(\ln CAP) + K \; . \; . \; . \; CAP_{s.e.} = 0.3 \qquad (3.1.16)$$

The test for Eq. 3.1.15 is:

$$\frac{(d - 1)}{s.e.} = t \text{ (at } n - 1); \quad t = \frac{0.1}{0.3} = + 0.3; \qquad (3.1.17)$$

The test for Eq. 3.1.16 is:

$$\frac{(f - 0)}{s.e.} = t \text{ (at } n - 1); \quad t = \frac{-0.1}{0.3} = -0.3. \qquad (3.1.18)$$

Thus, these tests would have indicated that neither coefficient was significant at a conventional level of probability. However, most computerized statistical packages, e.g., SAS and SPSS, routinely test regression coefficients against the zero interval, and this procedure would have resulted in a significant t value of 3 for the scaling coefficient in Eq. 3.1.15 -- a highly misleading result.

There seems to be considerable confusion in the literature concerning the above point. Additionally, some of the model specifications found in the literature do not allow one to estimate directly a scaling coefficient, i.e., an elasticity coefficient. Further, it is not obvious how one might make a valid significance test for a capacity coefficient in models that depart from log-log specifications.

The results of a multiple-regression analysis of the cost (including IDC) per kW for nuclear units, employing the model given by Eq. 3.1.11, are shown in Table 3.1.1. The coefficient for LMW (ln CAP, in megawatts) indicates a scaling exponent minus one (P - 1) of -0.055, but the coefficient is not significantly different (statistically) from zero. Thus, the scaling exponent P is 0.945 (which is not significantly different from one), indicating very little economy of scale.

Table 3.1.1. Multiple-Regression Analysis for Total Cost (1984 $) per kW for Nuclear Units Using Basic Model.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	15.11999111	3.02399822	41.769	0.0001
ERROR	83	6.00911151	0.07239893		
C TOTAL	88	21.12910262			

ROOT MSE	0.2690705	R-SQUARE	0.7156
DEP MEAN	7.200759	ADJ R-SQ	0.6985
C.V.	3.736697		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.86254808	0.97750041	7.021	0.0001
FIRST	1	0.16040205	0.05915277	2.712	0.0081
SOUTH	1	-0.22794890	0.05891559	-3.869	0.0002
E79	1	0.28534672	0.09823039	2.905	0.0047
LMW	1	-0.05481056	0.14564510	-0.376	0.7076
T65	1	0.09338170	0.01558142	5.993	0.0001

The coefficient of T65 (year of construction start - 1965) indicates an annual cost increase of 9.3%, statistically significant, as are all other coefficients.

The coefficient of 0.16 for the dummy variable FIRST indicates the cost factor for a first unit is $e^{0.16}$, which is 1.174, and that the cost of a first unit is an estimated 17.4% greater than the cost of a second, planned unit.

For a unit in the South the coefficient for the dummy variable indicates a cost factor of 0.796, or that the cost of a unit in the South is 20.4% less than a unit not in the South. The dummy variable E79 is equal to one for units on which construction was completed after the March, 1979, accident at Three-Mile Island, and the coefficient of 0.285 indicates a cost multiplying factor of 1.33, or that units completed after TMI cost 33% more than units with the same construction start date but completed before TMI.

For coal-fired units, with the model given by Eq. 3.1.12 employed, the regression results are shown in Table 3.1.2 for the cost (including IDC) per kW. The coefficient for LMW is -0.065, not statistically significant at the 0.1 probability level. Thus, a scaling exponent of 0.935 is indicated, but it is not significantly different from one.

All other coefficients are significant at the 0.05 level. The annual cost increase is indicated to be 4.2% per year, a first unit costs more by an estimated 38.5% than a second unit, and a unit in the South costs 10.0% less than one not in the South. The coefficient for the dummy variable DFGD indicates that a unit with FGD costs 23.1% more than a unit without FGD.

Table 3.1.2. Multiple-Regression Analysis for Total Cost (1984 $) per kW for Coal-Fired Units Using Basic Model.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	7.49081691	1.49816338	23.287	0.0001
ERROR	102	6.56209401	0.06433426		
C TOTAL	107	14.05291092			

ROOT MSE	0.253642	R-SQUARE	0.5330
DEP MEAN	6.718009	ADJ R-SQ	0.5102
C.V.	3.775553		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.39469127	0.40683298	15.718	0.0001
FIRST	1	0.32603084	0.05076746	6.422	0.0001
SOUTH	1	-0.10514144	0.05098039	-2.062	0.0417
DFGD	1	0.20785660	0.05339199	3.893	0.0002
LMW	1	-0.06514124	0.06006200	-1.085	0.2807
T65	1	0.04164382	0.01249001	3.334	0.0012

3.2 LINEAR MODEL

An additive model was used in a linear regression analysis by Mooz (2) in a 1978 study of investment costs of light water reactor power plants. He calculated costs, based on regression results for which he indicated questionable statistical significance of the size coefficient, for sizes of 500, 600, 1100, and 1200 MW(e). Then using the traditional cost-size scaling relationship, he calculated scaling exponent values. Selecting 500 and 600 MW(e) sizes, the resulting exponent was about 0.8. Selecting 1100 and 1200 MW(e), the calculated scaling exponent was about 0.5. Selecting the sample extremes of 500 and 1100 MW(e), the resulting exponent value was about 0.7.

In a second study by Mooz (3) in 1979, an additive model was again used in a linear regression analysis, and a multiplicative model was also used. In each of these models, he indicated that the size term lacked statistical significance in the regressions for cost/kW(e), and he concluded that the results indicated no sizeable economy of scale in unit costs as the size increases.

In a regression analysis by Nieves, et al. (4), an additive model similar to the one used by Mooz was employed in a study in which the main focus was on the cost of electricity. Nuclear capital cost data from the 1978 study by Mooz were used in the regression, and the authors stated that the data set was composed of 39 units which began commercial operation from 1968 to 1977. Dummy variables were used to indicate a partial turnkey arrangement, presence of a cooling tower, and location in the Northeast. Mooz indicated the extremes of capacities in the sample were 500 MW(e) and 1100 MW(e). Using these extremes and selecting variables to determine the most favorable scaling exponent, as determined by the ratio of costs for 500-MW(e) and 600-MW(e) units, the calculated value is 0.257 for units with cooling towers, completed in 1977, located in the Northeast, and not a turnkey unit. However, using calculated costs for turnkey units of 500 and 600 MW(e) capacities, completed in 1970, without cooling towers, and located in the Northeast, the calculated scaling exponent is 5.17. For the latter two units completed in 1968 or 1969, the calculated costs for the units are negative and have no meaning. Any estimate of a scaling exponent calculated from this additive model should be limited to a narrow range near the middle of the range of the data, near a 1973 commercial operation date and a capacity of 800 MW(e). Even there the inordinately large numerical value of the coefficient for the turnkey dummy variable results in a change in a calculated scaling exponent from a value of about 0.48 to a value of 0.74.

In order to compare scaling exponents calculated from an additive model with the results obtained by the multiplicative model, with both models applied to the same data set, the CRA-EEI data were subjected to a regression analysis using the additive model. The results for nuclear units are shown in Table 3.2.1. A multiplicative model, in which the same variables are used, is shown in Table 3.2.2.

From the additive model, for a unit which is not a first unit, is not located in the South, and on which construction began in 1971 (the approximate mid-range for the data), a scaling exponent of 1.22 is calculated on the basis of costs of units with capacities of 1000 and 800 MW. If the unit is a first unit, the calculated exponent is 1.02. These values compare with the single value of 1.06 determined by the multiplicative model in Table 3.2.2. All of these exponent values indicate diseconomy of scale.

For coal-fired units, the regression results of an additive model are shown in Table 3.2.3. For a unit which is not a first unit, is not located in the South, does not have FGD, and with construction starting in 1978 (the approximate mid-range of the data), the calculated scaling exponent is 1.05 on the basis of calculated costs of 400-MW and 800-MW units. For a first unit with FGD, the calculated scaling exponent is 0.67. These values compare with a single value of 0.93 indicated by the multiplicative model shown in Table 3.2.4.

Although an additive model may have some limited use in the determination of exponent values in some rather narrow range (with uncertain identification), near the middle of the range of the data, the model does not appear to be particularly suitable in determining scaling exponents or a time trend of costs.

Table 3.2.1. Regression Analysis for Total Cost (1984 $) for Nuclear Units, Based on Additive Model.

DEP VARIABLE: C84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	5.27086E+13	1.31771E+13	59.177	0.0001
ERROR	84	1.87047E+13	222675369016		
C TOTAL	88	7.14133E+13			

ROOT MSE	471884.9	R-SQUARE	0.7381
DEP MEAN	1491761	ADJ R-SQ	0.7256
C.V.	31.63274		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-1329932.82	264561.59	-5.027	0.0001
MW	1	1772.36410	297.71662	5.953	0.0001
FIRST	1	253522.35	103460.75	2.450	0.0163
SOUTH	1	-278684.63	102983.81	-2.706	0.0082
T65	1	174486.81	19233.78181	9.072	0.0001

Table 3.2.2. Regression Analysis for Total Cost (1984 $) for Nuclear Units, Based on Multiplicative Model.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	26.37566277	6.59391569	83.669	0.0001
ERROR	84	6.62003413	0.07880993		
C TOTAL	88	32.99569690			

ROOT MSE	0.2807311	R-SQUARE	0.7994
DEP MEAN	14.03677	ADJ R-SQ	0.7898
C.V.	1.999969		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.00851866	0.97264011	6.178	0.0001
LMW	1	1.05973331	0.14628173	7.244	0.0001
FIRST	1	0.15252326	0.06165133	2.474	0.0154
SOUTH	1	-0.23713877	0.06138010	-3.863	0.0002
T65	1	0.12632751	0.01114709	11.333	0.0001

Table 3.2.3. Regression Analysis for Total Cost (1984 $) for Coal-Fired Units, Based on Additive Model.

DEP VARIABLE: C84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	2.81385E+12	562769845545	40.217	0.0001
ERROR	102	1.42731E+12	13993278496		
C TOTAL	107	4.24116E+12			

ROOT MSE	118293.2	R-SQUARE	0.6635
DEP MEAN	445303.7	ADJ R-SQ	0.6470
C.V.	26.56461		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-275611.24	79791.23308	-3.454	0.0008
MW	1	748.84472	66.06497798	11.335	0.0001
FIRST	1	134068.35	23677.76515	5.662	0.0001
SOUTH	1	-48918.40904	23775.61079	-2.058	0.0422
DFGD	1	95814.97527	24927.84415	3.844	0.0002
T65	1	19714.47749	5827.16400	3.383	0.0010

Table 3.2.4. Regression Analysis for Total Cost (1984 $) for Coal-Fired Units, Based on Multiplicative Model.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	20.67244375	4.13448875	64.266	0.0001
ERROR	102	6.56209401	0.06433426		
C TOTAL	107	27.23453776			

ROOT MSE	0.253642	R-SQUARE	0.7591
DEP MEAN	12.8948	ADJ R-SQ	0.7472
C.V.	1.96701		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.39469127	0.40683298	15.718	0.0001
LMW	1	0.93485876	0.06006200	15.565	0.0001
FIRST	1	0.32603084	0.05076746	6.422	0.0001
SOUTH	1	-0.10514144	0.05098039	-2.062	0.0417
DFGD	1	0.20785660	0.05339199	3.893	0.0002
T65	1	0.04164382	0.01249001	3.334	0.0012

3.3 INTERACTIVE VARIABLES

The use of a dummy variable in a multiple-regression model has been discussed previously as providing a term to show the effect of a characteristic or an effect (such as TMI, etc.). An interactive variable can be used to provide further information associated with such a characteristic or event, and can also allow for much greater latitude in the mathematical expressions in terms of the independent variables.

Stewart (5), in an analysis of coal-fired units, used as one of his continuous variables the natural logarithm of the difference between the heat rate and 6,000 Btu/kWh. In addition to the natural logarithm of capacity, he also used a mixed interactive variable which is the product of two continuous variables -- the natural logarithm of capacity and the natural logarithm involving the heat rate. The square of the natural logarithm of capacity allows a variation in the slope of the regression line on a plot of the natural logarithm of unit cost versus the natural logarithm of capacity. This slope, for example, for a heat rate of 9,500 Btu/kWh varies from -0.13 for a 400-MW unit to +0.12 for an 800-MW unit. The corresponding values of the scaling exponent P range from 0.87 to 1.12.

Heat rates were not available in the CRA-EEI data. However, other interactive variables were used to illuminate certain specific effects, such as the variation of the scaling exponent P with capacity and also with time. Also, products of dummy variables and continuous variables were used as interactive dummy variables to allow for different slopes of two lines representing units with different characteristics. For example, the slope of a line for a unit with FGD is allowed to be different from the slope for a non-FGD unit on a plot of the natural logarithm of unit cost versus time. Thus the annual percent increase in cost for these units of different characteristics is not constrained to be the same value.

One model incorporating several interactive variables, in a regression for nuclear plants, is shown as the first regression equation in Table 3.3.1. Although the F-values indicate several terms are not significant and should be dropped in seeking improvements in the model, it is recognized that the multiple appearance of a variable results in dilution of the significance of terms in which the variable occurs. It is interesting to note the implications of the coefficients of some of the interactive variables.

Table 3.3.1. Regression Analysis for Total Cost (1984 $) per kW for Nuclear Units, from a Backward Elimination Procedure on a Model Employing Interactive Variables.

BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE LC84KW

STEP 0 ALL VARIABLES ENTERED R SQUARE = 0.75328437 C(P) = 13.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	12	15.91622267	1.32635189	19.34	0.0001
ERROR	76	5.21287995	0.06859053		
TOTAL	88	21.12910262			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	47.47957840				
LMW	-13.17511407	6.81488211	0.25636351	3.74	0.0569
LMW2	1.04492406	0.51648059	0.28075375	4.09	0.0466
T65	1.21697926	0.88233201	0.13048675	1.90	0.1719
T652	-0.00561743	0.00593375	0.06147239	0.90	0.3468
FIRST	0.92693603	2.21993618	0.01195866	0.17	0.6775
SOUTH	-0.20762017	0.05881037	0.85486083	12.46	0.0007
E79	-2.15991023	4.90613244	0.01329404	0.19	0.6610
E79T65	-0.00008317	0.06163448	0.00000012	0.00	0.9989
T65FIR	0.01588503	0.02166100	0.03688780	0.54	0.4656
LMWT65	-0.15187693	0.12955461	0.09426317	1.37	0.2447
LMWFIR	-0.12761877	0.33292946	0.01007833	0.15	0.7026
LMWE79	0.33931455	0.68363665	0.01689734	0.25	0.6211

BOUNDS ON CONDITION NUMBER: 10312.83, 1083820

STEP 4 VARIABLE T65FIR REMOVED R SQUARE = 0.75081017 C(P) = 5.76216837

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	15.86394514	1.98299314	30.13	0.0001
ERROR	80	5.26515748	0.06581447		
TOTAL	88	21.12910262			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	50.98496964				
LMW	-14.03556366	6.12111286	0.34603523	5.26	0.0245
LMW2	1.09466728	0.46836091	0.35952108	5.46	0.0219
T65	0.94191352	0.36670827	0.43421220	6.60	0.0121
T652	-0.00612550	0.00396166	0.15734391	2.39	0.1260
FIRST	0.15425123	0.05652422	0.49012804	7.45	0.0078
SOUTH	-0.20498099	0.05671591	0.85968396	13.06	0.0005
LMWT65	-0.10992919	0.05540457	0.25909339	3.94	0.0507
LMWE79	0.02557678	0.01480365	0.19646060	2.99	0.0879

BOUNDS ON CONDITION NUMBER: 3012.66, 153268.8

STEP 5 VARIABLE T652 REMOVED R SQUARE = 0.74336338 C(P) = 6.05612820

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	15.70660123	2.24380018	33.52	0.0001
ERROR	81	5.42250139	0.06694446		
TOTAL	88	21.12910262			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	50.35553218				
LMW	-13.94485195	6.17315349	0.34160822	5.10	0.0266
LMW2	1.09985098	0.47235243	0.36295270	5.42	0.0224
T65	1.07765273	0.35908849	0.60293342	9.01	0.0036
FIRST	0.15755634	0.05696662	0.51208917	7.65	0.0070
SOUTH	-0.20861483	0.05715159	0.89196612	13.32	0.0005
LMWT65	-0.14203448	0.05180561	0.50320921	7.52	0.0075
LMWE79	0.02737853	0.01488387	0.22651814	3.38	0.0695

BOUNDS ON CONDITION NUMBER: 3012.506, 128327.5

ALL VARIABLES IN THE MODEL ARE SIGNIFICANT AT THE 0.1000 LEVEL.

The four interactive dummy variables indicate different values of scaling exponents and the cost time trend for first units and for units finished after TMI. The scaling exponent minus one is determined by the partial derivative of the logarithm of cost per kW with respect to the natural logarithm of capacity, and the coefficient of -0.127619 indicates that the scaling exponent for a first unit is less than for a planned second unit by a magnitude of 0.1276. Similarly, the scaling exponent for a unit finished after TMI is indicated to be higher by 0.339 than units finished before TMI.

The annual fractional change in cost, as determined by the partial derivative of the natural logarithm of cost per kW with respect to time, increases by 0.015885 (1.5885%) more each year for a first unit than for a second planned unit. For units finished after TMI, the annual percent change is 0.008% less than for units finished before TMI, as indicated by the coefficient of -0.00008317.

For a unit on which construction started in 1970 and was completed after TMI, the cost exceeds the cost of a unit completed before TMI by an estimated 20.2% for a 1000-MW unit, and by 27.8% for a 1200-MW unit.

A reminder is in order, at this point, that these results should be viewed skeptically because of the poor statistical significance of the coefficients of several terms in the regression results.

The term LMW2 is the square of LMW (the natural logarithm of capacity, in MW) and produces a term in the scaling exponent P (the slope plus one) which has 2 times 1.044924 as the coefficient of LMW, thus giving a scaling exponent value which varies with LMW. The interactive term LMWT65 is the product of LMW and T65, and results in a term in the scaling exponent which is the coefficient -0.151877 times T65, yielding a decrease in the scaling exponent of 0.151877 each year for any specific capacity. Example calculations of the scaling exponent, over the range of the data, are shown in Table 3.3.2.

Table 3.3.2. The Scaling Exponent P for Second,* Planned Nuclear Units Calculated from Table 3.3.1, Step 0**, by Year of Construction Start.

CAP (MW)	1967	1970	1973	1976***
600	0.89	0.43	-0.02	-0.14
800	1.49	1.04	0.58	0.46
1000	1.96	1.50	1.05	0.93
1200	2.34	1.88	1.43	1.31

* Subtract 0.13 for a first unit.

** The F-values for the regression results in Step 0 indicate dubious significance, at best, for some terms and the calculated scaling exponents should be viewed accordingly.

*** For plants completed after TMI.

The term T652 is the square of T65 (the start year minus 1965), and produces a term in the annual percent change in cost (annual percent change in cost is 100 times the partial derivative of the natural logarithm of cost per kW with respect to the year of construction start) which has (100)(2)(-0.00561743) as the coefficient of T65. This gives an annual percent change as a function of time. Specifically, this results in a reduction each year of 1.123486 percent in the annual percent change in cost. The interactive term LMWT65 results in a term which is 100 times the coefficient, -0.151877, times LMW, with the negative sign indicating that the annual percent change decreases with increasing capacity. Example calculations of the annual percent change, over the range of the data, are shown in Table 3.3.3.

Table 3.3.3. Annual Percent Change in Capital Investment Costs (1984 $) for Planned, Second* Nuclear Units Calculated from Table 3.3.1, Step 0**, by Year of Construction Start.

CAP (MW)	1967	1970	1973	1976***
600	22.3%	18.9%	15.6%	12.2%
800	17.9%	14.6%	11.2%	7.8%
1000	14.5%	11.2%	7.8%	4.4%
1200	11.8%	8.4%	5.0%	1.7%

* For a first unit, add 1.6%.

** The F-values for the regression results in this table indicate dubious significance, at best, for some terms and the calculated values of annual percent change in cost should be viewed accordingly.

*** For units completed after TMI.

The values tabulated in Tables 3.3.2 and 3.3.3 can be seen as the slopes of lines on the surface in the three-dimensional representation in Figure 3.3.1, where ln C/KW is plotted on the vertical axis, and time and ln CAP are plotted on the axes in the horizontal plane.

Only two continuous independent variables are used in the regression equation. These are the time variable, and the natural logarithm of capacity. All other independent variables are dummy variables. The scaling exponent minus one, and the annual percent change in cost are each partial derivatives of the natural logarithm of cost with respect to one of these continuous independent variables, holding the other constant. Thus, the slope of a line in a plane parallel to one of the coordinate planes represents one of these partial derivatives, and can be seen as the slope of one of the net lines at a point.

The plot represents the estimated ln C/KW for a unit completed before TMI, not in the South, and not a first unit. The surface for a unit in the South would be an identical surface, displaced downward, for a unit completed before TMI and not a first unit. For a unit completed after TMI, or for a first unit, the surface would be different but would look similar to the one shown.

The additional regression equations in Table 3.3.1 are selected steps in a backward elimination procedure in which each step consists of removal of the variables shown in the previous step to be the least significant (statistically) in explaining the cost. It is interesting to note that the equation in Step 4 retains the squared terms, involving capacity and time, and the statistical significance of each capacity term and of each time term has increased with the dropping of four terms. Yet the values of the scaling exponent and the annual percent cost change are relatively unchanged compared with the original model. This can be seen by the example calculations shown in Tables 3.3.4 and 3.3.5.

Figure 3.3.1. Plot of ln C/KW vs. time and ln CAP for nuclear units.

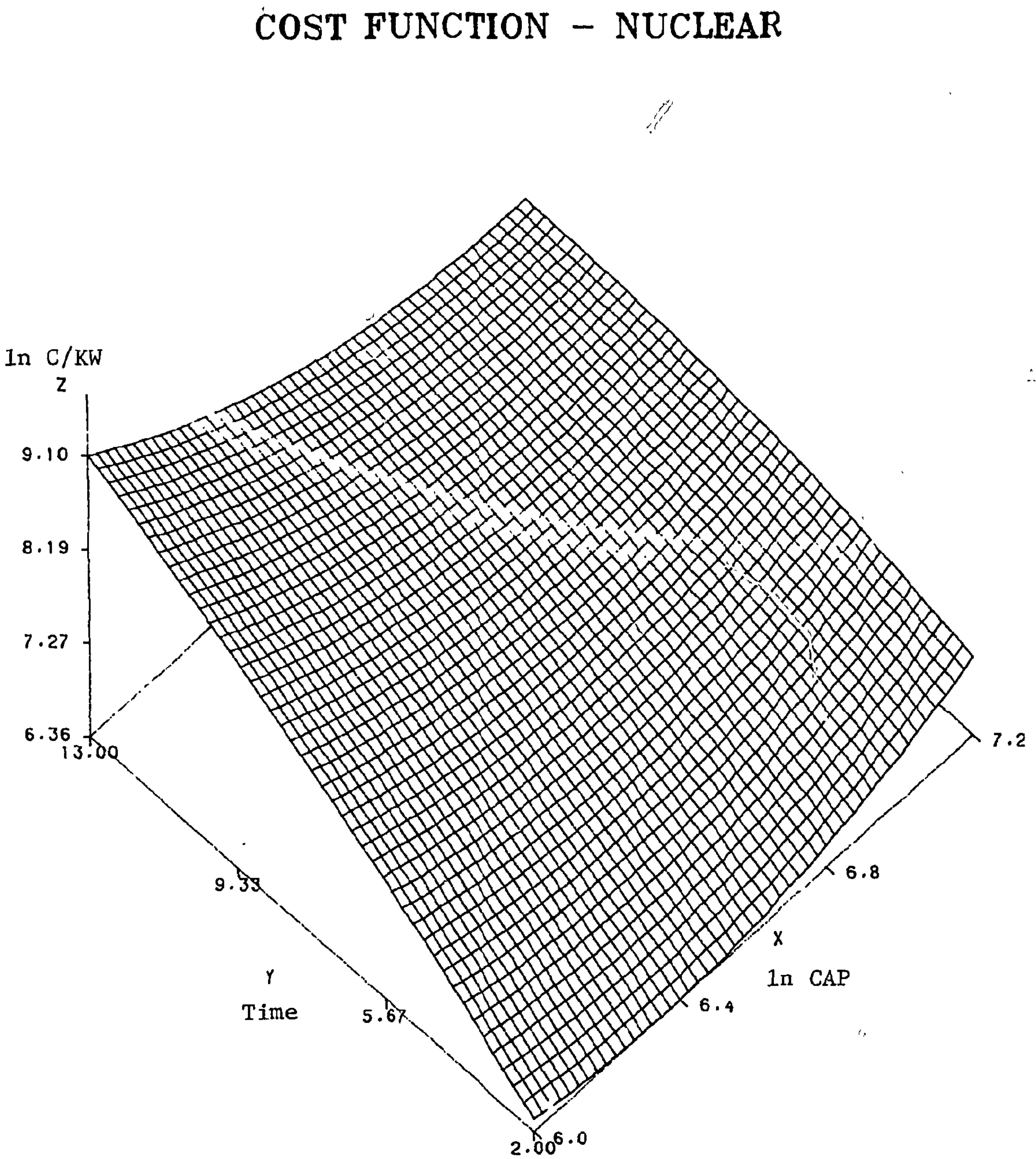


Table 3.3.4. The Scaling Exponent for Second Nuclear Units Calculated from the Step 4 Equation in Table 3.3.1 by Year of Construction Start.

CAP (MW)	1967	1970	1973	1976*
600	0.75	0.42	0.09	-0.21
800	1.38	1.05	0.72	0.42
1000	1.87	1.54	1.21	0.90
1200	2.27	1.94	1.61	1.30

* For units completed after TMI.

Table 3.3.5. Annual Percent Change in Capital Investment Cost (1984 $) for Planned, Second Nuclear Units Calculated from Step 4 Eq. in Table 3.3.1 by Year of Construction Start.

CAP (MW)	1967	1970	1973	1976
600	21.4%	17.7%	14.1%	10.4%
800	18.3%	14.6%	10.9%	7.2%
1000	15.8%	12.1%	8.5%	4.8%
1200	13.8%	10.1%	6.4%	2.8%

The dummy interactive variable has a coefficient of 0.02557678, and the product of this coefficient and the natural logarithm of 600 is 0.1636, which indicates that 600-MW units completed after TMI experienced a cost increase of 17.8% compared with units completed before TMI. For 1200-MW units, the corresponding increase indicated is 19.9%.

The Step 4 model does not contain as an interactive dummy variable the product of the time variable and the TMI dummy variable, and therefore does not provide a different annual percent change in cost for units completed after TMI compared with those completed before TMI.

The Step 4 model contains the capacity in four terms and the time variable (year of construction start) in three terms, and the time-squared term is the least significant (statistically) of all the terms in the equation. This term is dropped in Step 5, and the statistical significance of each of the two remaining terms containing the time variable is improved substantially. The dependency of the scaling exponent on capacity is relatively unchanged, as indicated by the coefficient of LMW2. However, the decrease with time is 0.142 per year, compared with 0.11 in the Step 4 equation. This may be associated with a multicollinearity problem involving a correlation between capacity and the year of construction start, which is discussed in the following section. This also suggests that the use of a highly interactive model may not be warranted in the analysis of this data set, which contains only 89 datum points and has pronounced variance, as previously indicated by the plots of adjusted data. However, the selected use of interactive terms can serve a useful purpose with judicious application, particularly in determining the algebraic signs of some coefficients even if the magnitude of the coefficients may be subject to large variations.

With the simplification resulting from the removal of all interactive terms, the first equation in Table 3.3.6 (same as Table 3.1.1) is obtained. The results indicate a first unit costs 17.4% more compared with 16.7% more in the Step 4 model, and that units in the South cost 20.4% less compared with 18.5% less in the Step 4 model. However, this model indicates that units completed after TMI cost 33% more than units completed before TMI, while the coefficient on the dummy interactive variable provides the only TMI indicator in the Step 4 model and indicates only a 17.8% to 20.1% increase (over the capacity range of the data) for units completed after TMI, which is very likely misleading. It should be noted that the dummy variables for FIRST and SOUTH did not appear in interactive variables and the results from the two models under discussion were similar for these variables.

In the first regression equation in Table 3.3.6, the coefficient of LMW has a small magnitude and is not statistically significant. Thus, the "average" scaling exponent of (1.0 - 0.055) is 0.945 and is not significantly different from 1.0 and indicates that there is no significant economy of scale for the nuclear units in this data set of 89 units.

The second equation in Table 3.3.6 does not have the unit capacity included, and there is a slight adjustment in the remaining coefficients to accommodate the omission of the capacity as an independent variable.

An analogous interactive model for coal-fired plants is shown as the first regression equation in Table 3.3.7. The results indicate that the scaling exponent for a first unit is less (by 0.10597) than for a second unit, and that it is less for an FGD unit (by 0.08143) than for a non-FGD unit. The coefficients also indicate the annual percent change in cost for a unit is 3.2304% less if the unit is a first unit, and 1.9656% more for an FGD unit. Again, a reminder is given that these results should be viewed

Table 3.3.6. Regression Analysis for Total Cost (1984 $) per kW for Nuclear Units, Based on Models Without Interactive Variables.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	15.11999111	3.02399822	41.769	0.0001
ERROR	83	6.00911151	0.07239893		
C TOTAL	88	21.12910262			

ROOT MSE	0.2690705	R-SQUARE	0.7156
DEP MEAN	7.200759	ADJ R-SQ	0.6985
C.V.	3.736697		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	6.86254808	0.97750041	7.021	0.0001
FIRST	1	0.16040205	0.05915277	2.712	0.0081
SOUTH	1	-0.22794890	0.05891559	-3.869	0.0002
E79	1	0.28534672	0.09823039	2.905	0.0047
LMW	1	-0.05481056	0.14564510	-0.376	0.7076
T65	1	0.09338170	0.01558142	5.993	0.0001

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	15.10973769	3.77743442	52.714	0.0001
ERROR	84	6.01936494	0.07165911		
C TOTAL	88	21.12910262			

ROOT MSE	0.2676922	R-SQUARE	0.7151
DEP MEAN	7.200759	ADJ R-SQ	0.7015
C.V.	3.717555		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	6.49604976	0.08366914	77.640	0.0001
FIRST	1	0.16402212	0.05806639	2.825	0.0059
SOUTH	1	-0.23076509	0.05813906	-3.969	0.0002
E79	1	0.27533835	0.09407740	2.927	0.0044
T65	1	0.09271471	0.01540100	6.020	0.0001

Table 3.3.7. Regression Analyses for Total Cost (1984 $) per kW for Coal-Fired Units, From a Backward Elimination Procedure on a Model Employing Interactive Variables.

BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE LC84KW

STEP 0 ALL VARIABLES ENTERED R SQUARE = 0.59006080 C(P) = 13.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	12	8.29207180	0.69100598	11.40	0.0001
ERROR	95	5.76083912	0.06064041		
TOTAL	107	14.05291092			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.83034663				
LMW	3.10262186	1.39602177	0.29952664	4.94	0.0286
LMW2	-0.26553246	0.11154939	0.34360777	5.67	0.0193
T65	-0.32600235	0.27577755	0.08473948	1.40	0.2401
T652	0.01439743	0.00726182	0.23836427	3.93	0.0503
FIRST	1.40527655	0.88935599	0.15140300	2.50	0.1174
DFGD	0.40404091	0.85826648	0.01343905	0.22	0.6389
SOUTH	-0.13124178	0.05205345	0.38548481	6.36	0.0134
T65FGD	0.01965602	0.02976865	0.02643841	0.44	0.5107
T65FIR	-0.03230441	0.02574014	0.09551338	1.58	0.2125
LMWT65	0.00187449	0.03279490	0.00019811	0.00	0.9545
LMWFIR	-0.10597136	0.12776467	0.04171743	0.69	0.4089
LMWFGD	-0.08142774	0.12438317	0.02598864	0.43	0.5143

BOUNDS ON CONDITION NUMBER: 611.0754, 88965.82

STEP 4 VARIABLE LMWFIR REMOVED R SQUARE = 0.58447299 C(P) = 6.29492649

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	8.21354692	1.02669337	17.41	0.0001
ERROR	99	5.83936399	0.05898347		
TOTAL	107	14.05291092			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.61428771				
LMW	3.11380473	1.29137622	0.34293162	5.81	0.0177
LMW2	-0.27151685	0.10879657	0.36736141	6.23	0.0142
T65	-0.32508189	0.15374809	0.26369168	4.47	0.0370
T652	0.01490809	0.00633743	0.32639833	5.53	0.0206
FIRST	0.68645461	0.31976726	0.27182289	4.61	0.0343
SOUTH	-0.12821359	0.04933958	0.39829756	6.75	0.0108
T65FGD	0.01185162	0.00439323	0.42925645	7.28	0.0082
T65FIR	-0.02766592	0.02467296	0.07416145	1.26	0.2649

BOUNDS ON CONDITION NUMBER: 518.7273, 24639.15

STEP 5 VARIABLE T65FIR REMOVED R SQUARE = 0.57919569 C(P) = 5.51789724

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	8.13938547	1.16276935	19.66	0.0001
ERROR	100	5.91352544	0.05913525		
TOTAL	107	14.05291092			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-0.52968839				
LMW	2.99084392	1.28881175	0.31973910	5.41	0.0221
LMW2	-0.26066968	0.10850498	0.34129362	5.77	0.0181
T65	-0.27685096	0.14779854	0.20749052	3.51	0.0640
T652	0.01247182	0.00596100	0.25886144	4.38	0.0389
FIRST	0.33206834	0.04869175	2.75036732	46.51	0.0001
SOUTH	-0.12250899	0.04913969	0.36755094	6.22	0.0143
T65FGD	0.01263167	0.00434338	0.50016335	8.46	0.0045

BOUNDS ON CONDITION NUMBER: 514.6263, 19543.52

ALL VARIABLES IN THE MODEL ARE SIGNIFICANT AT THE 0.1000 LEVEL.

with skepticism because of the poor statistical significance of the coefficients of several terms in the regression results, and the multicollinearity problem.

Similar to the results given for nuclear units, the scaling exponent and annual percent change in cost vary with unit capacity and with the year of construction start. Example calculations of these values, over the range of the data, are given in Tables 3.3.8 and 3.3.9.

Table 3.3.8. The Scaling Exponent for Planned, Second* Coal-Fired Units, Without FGD**, Calculated from the Regression Results in Table 3.3.7, Step 0***, by Year of Construction Start.

CAP (MW)	1973	1976	1979	1982
200	1.30	1.31	1.32	1.32
400	0.94	0.94	0.95	0.95
600	0.72	0.73	0.73	0.74
800	0.57	0.57	0.58	0.58

* For first units, subtract 0.105971.

** For units with FGD, subtract 0.081428.

*** The F-values for the regression results in this table indicate dubious statistical significance, at best, and the results tabulated here should be viewed accordingly.

Table 3.3.9. Annual Percent Change in Capital Investment Costs (1984 $) for Planned, Second* Coal-Fired Units, Without FGD**, Calculated from the Regression Results in Table 3.3.7, Step 0***, by Year of Construction Start.

CAP (MW)	1973	1976	1979	1982
200	-8.6%	0.1%	8.7%	17.3%
400	-8.4%	0.2%	8.8%	17.5%
600	-8.4%	0.3%	8.9%	17.5%
800	-8.3%	0.3%	9.0%	17.6%

* For first units, subtract 3.2%.

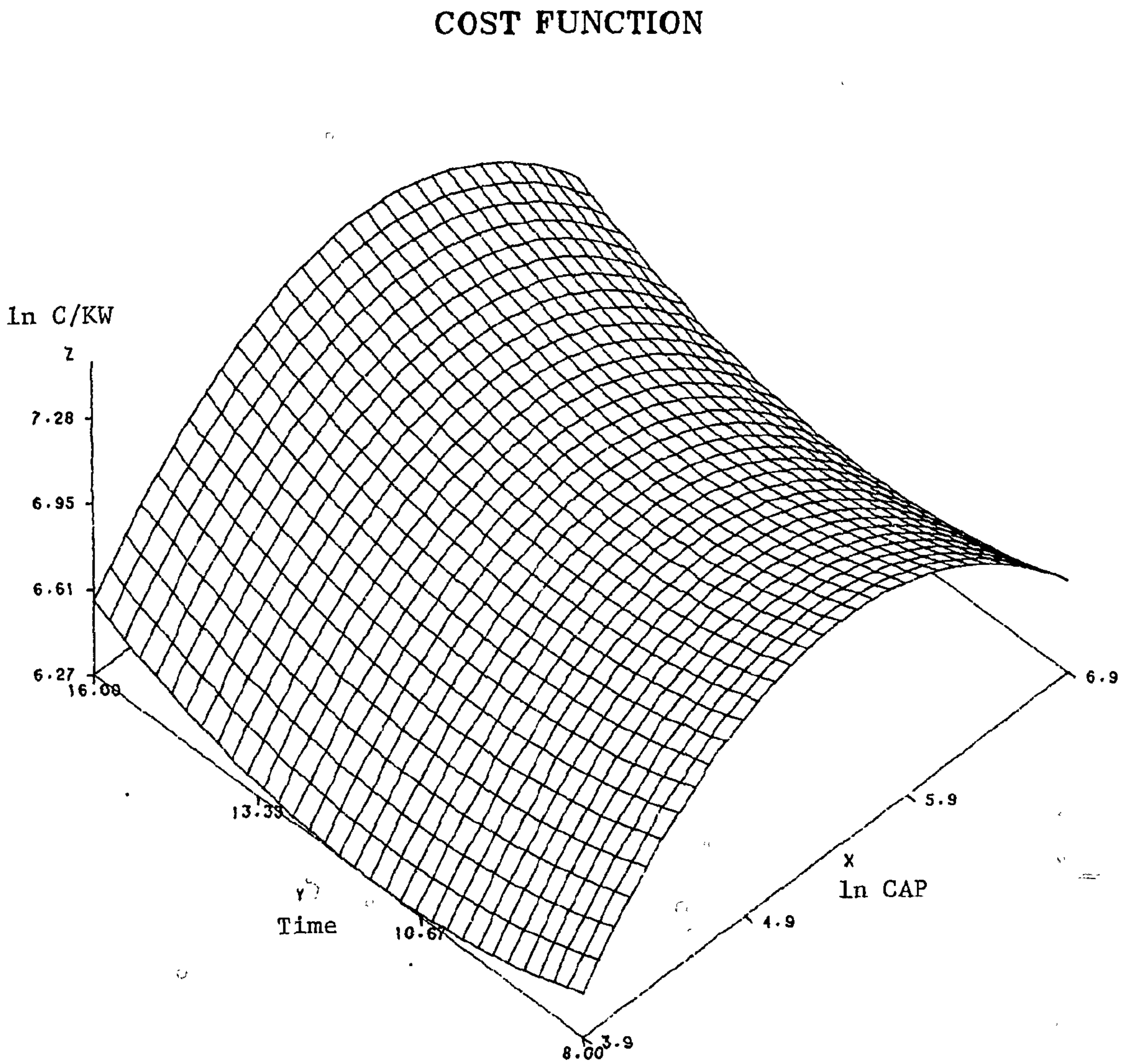
** For units with FGD, add 2.0%.

*** The F-values for the regression results in Table 3.3.7, Step 0***, indicate dubious statistical significance, at best, for some coefficients and the results tabulated here should be viewed accordingly.

The values tabulated in these two tables may be seen as slopes in the three-dimensional representation in Figure 3.3.2, which is similar to the plot for nuclear units. It is interesting to note, however, that the ridge of the "saddle" is oriented approximately 90^{o} from the ridge of the saddle seen in the plot for the nuclear units.

In contrast with the results for nuclear units, which indicated a better scale economy in the range of smaller capacities, the results of the regressions for coal-fired units indicate better economy of scale for units in the higher capacity range. Also, the cost trend indicates the annual percent change in costs to be algebraically increasing with time, whereas the results for the nuclear units indicated the opposite trend. However,

Figure 3.3.2. Plot of ln C/KW vs. time and ln CAP for coal-fired units.



the poor statistical significance of these results and the possible multicollinearity problem are again pointed out.

In the Step 4 and Step 5 equations in this backward elimination procedure, the coefficients of the squared terms are little different from their respective values in the initial equation. Therefore, the range of variation in the scaling exponent with capacity and the range of variation in the annual percent change in cost with time are similar to those resulting from the original equation. The coefficient of the dummy variable SOUTH, which appears as a variable only once in each equation, is also similar in the Step 4 and Step 5 equations and the original equation.

In the Step 4 and Step 5 equations, the differential for FGD is contained in only one term, an interactive term, which indicates an annual percent change in cost 1.2% greater than for a unit without FGD. Over the range of the data, the FGD increment is 10% for 1973 to 24% for units with construction started in 1982.

With the two squared terms and the interactive term removed, the regression results are shown as the first equation in Table 3.3.10 (same as Table 3.1.2). The coefficient for a first unit changed very little. For a unit in the South, the reduction in cost is 10.0% compared with 11.5% indicated by the Step 5 equation. The coefficient of 0.2079 for FGD indicates an increase of 23.1% over units without FGD, compared with about a 17% increase at the mid-range in the Step 5 equation in which the FGD increase was totally dependent on an interactive term. The coefficient on T65 indicates an average percent increase in cost of 4.2% annually.

The coefficient of LMW is small and has less significance than any term in this regression. It indicates an "average" scaling exponent of (1.0 - 0.065), or 0.935, and therefore no significant economy of scale for the coal-fired units in this data set of 108 units.

The unit capacity is omitted in the second regression equation in Table 3.3.10, and results in a slight adjustment in the remaining coefficients.

Table 3.3.10. Regression Analysis for Total Cost (1984 $) per kW for Coal-Fired Units, Based on Models Without Interactive Variables.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	5	7.49081691	1.49816338	23.287	0.0001
ERROR	102	6.56209401	0.06433426		
C TOTAL	107	14.05291092			

ROOT MSE	0.253642	R-SQUARE	0.5330
DEP MEAN	6.718009	ADJ R-SQ	0.5102
C.V.	3.775553		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.39469127	0.40683298	15.718	0.0001
FIRST	1	0.32603084	0.05076746	6.422	0.0001
SOUTH	1	-0.10514144	0.05098039	-2.062	0.0417
DFGD	1	0.20785660	0.05339199	3.893	0.0002
LMW	1	-0.06514124	0.06006200	-1.085	0.2807
T65	1	0.04164382	0.01249001	3.334	0.0012

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	7.41514150	1.85378537	28.766	0.0001
ERROR	103	6.63776942	0.06444436		
C TOTAL	107	14.05291092			

ROOT MSE	0.2538589	R-SQUARE	0.5277
DEP MEAN	6.718009	ADJ R-SQ	0.5093
C.V.	3.778783		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	5.98458151	0.15022500	39.837	0.0001
FIRST	1	0.32670736	0.05080705	6.430	0.0001
SOUTH	1	-0.10903973	0.05089702	-2.142	0.0345
DFGD	1	0.21303674	0.05322341	4.003	0.0001
T65	1	0.04219030	0.01249052	3.378	0.0010

3.4 MULTICOLLINEARITY

A multicollinearity problem arises from some degree of correlation between selected explanatory, or independent, variables. There is a tendency for a capacity trend with time, for example. In addition, there is some relationship between the capacity and FGD, and between capacity and first units. There is probably, also, a correlation between capacity and geographical location such as SOUTH, for example.

Any interrelationship between variables, even weakly related, becomes more intricately intertwined with increasing sophistication of regression models. The use of a highly interactive model, such as the models explored in the previous section, may create unrealistic expectations of the available data. Some insight into the relationship between the capacity of units in the CRA-EEI data file and the year of construction start is provided by regression analyses which estimate ln CAP (the form of the capacity variable of primary interest in the cost regressions in this report) as a function of time. The data for nuclear units and for coal-fired units were separately subjected to these analyses using a linear model in time, and also a two-degree polynomial in time.

The regression results for the nuclear units are shown in Table 3.4.1, in which t-values indicate the linear equation is the more significant explanatory model. Example values of capacities, over the time range of these data, calculated from this equation (the first equation in the table) are shown in Table 3.4.2.

The regression results for the coal-fired units are shown in Table 3.4.3, with the two-degree polynomial indicated (by the highly significant coefficient for each time term) to be the best estimator of capacity. Example values of capacities, over the time range of these data, calculated from this equation (the second regression equation in Table 3.4.3) are shown in Table 3.4.4.

Table 3.4.1. Regression Analyses for Unit Capacity (in megawatts), as a Function of Time, for Nuclear Units.

DEP VARIABLE: LMW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1.18930199	1.18930199	26.779	0.0001
ERROR	88	3.90828558	0.04441234		
C TOTAL	89	5.09758756			

ROOT MSE	0.2107423	R-SQUARE	0.2333
DEP MEAN	6.838878	ADJ R-SQ	0.2246
C.V.	3.081534		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.59632574	0.05186940	127.172	0.0001
T65	1	0.03764330	0.007274337	5.175	0.0001

DEP VARIABLE: LMW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	1.19672594	0.59836297	13.345	0.0001
ERROR	87	3.90086162	0.04483749		
C TOTAL	89	5.09758756			

ROOT MSE	0.2117486	R-SQUARE	0.2348
DEP MEAN	6.838878	ADJ R-SQ	0.2172
C.V.	3.096248		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.64339299	0.12686922	52.364	0.0001
T65	1	0.02081181	0.04200507	0.495	0.6215
T652	1	0.001207342	0.002967107	0.407	0.6851

Table 3.4.2. Capacity of Nuclear Units Calculated from the First Equation in Table 3.4.1 by Year of Construction Start.

Year	1967	1970	1973	1976
Capacity (MW)	790	884	990	1108

Table 3.4.3. Regression Analyses for Unit Capacity (in megawatts), as a Function of Time, for Coal-Fired Units.

DEP VARIABLE: LMW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.08814202	0.08814202	0.515	0.4747
ERROR	106	18.15445958	0.17126849		
C TOTAL	107	18.24260159			

ROOT MSE	0.413846	R-SQUARE	0.0048
DEP MEAN	6.17679	ADJ R-SQ	-0.0046
C.V.	6.700017		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.34732723	0.24103325	26.334	0.0001
T65	1	-0.01344999	0.01874861	-0.717	0.4747

DEP VARIABLE: LMW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	0.79829692	0.39914846	2.403	0.0954
ERROR	105	17.44430468	0.16613624		
C TOTAL	107	18.24260159			

ROOT MSE	0.4075981	R-SQUARE	0.0438
DEP MEAN	6.17679	ADJ R-SQ	0.0255
C.V.	6.598867		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	9.14252338	1.37265666	6.660	0.0001
T65	1	-0.47282441	0.22295494	-2.121	0.0363
T652	1	0.01832902	0.008865332	2.067	0.0411

Table 3.4.4. Capacity of Coal-fired Units Calculated from the Second Equation in Table 3.4.3 by Year of Construction Start.

Year	1973	1976	1979	1982
Capacity (MW)	687	473	452	603

The results presented here do not provide a solution to the multicollinearity problem, but merely suggest that an effort should be made to select analyses which can substantially reduce the problem and attempt to verify the validity of the more general model. Such an effort is described in Sections 3.7, 3.8 and 3.9 where analyses are performed cross-sectionally (data divided into short time intervals and time omitted as an explanatory variable in the regression analysis of each segment of the data), by partitioning the data by capacities (dividing data into narrow ranges of capacities and omitting capacity as an explanatory variable), and by partitioning the data for coal-fired plants into a set containing units with FGD and a set containing units without FGD.

A problem somewhat similar to multicollinearity is the specification error of including a dependent variable as an "independent" variable in a regression equation for a dependent variable of interest. For example, cost (in constant dollars), cubic yards of concrete required, tons of steel, and duration of construction may each be a function of time, the unit size, and other independent variables. Although the equations for these dependent variables can be solved independently, the erroneous inclusion of duration (for example) as an "independent" variable in the cost equation results in simultaneity bias, or biased estimators (coefficients), when the coefficients are estimated by an ordinary least squares solution. Valid coefficients may be obtained if the equations are estimated simultaneously (by a two-stage least squares solution, for example). Alternately, if each equation is solved independently and then the expression for duration is substituted into the cost equation, the resulting equation has identical coefficients. The simultaneous least squares solution is therefore redundant, since the same results are obtained by an ordinary least squares solution of an equation based on a properly specified model. This is further discussed in Section 3.6.

3.5 TIME VARIABLE SPECIFICATION

The time variable selection for power plant cost regression analyses reported in the literature consists principally of three dates. These are the date of the start of construction (or date of issuance of a construction permit), either the date of the completion of construction or the time at which the unit goes into commercial operation, and a mid-point of construction taken to be the average of the first two dates.

As discussed in Section 3.1, some feel that the date of construction start represents the time which better establishes a commonality in design of units with respect to the advance of the applicable technology and the regulatory requirements imposed.

As plants are delayed and attendant time-related costs add on to the cost of a unit, there is a tendency for the final cost of units on which construction is completed in approximately the same time frame to be more closely related, irrespective of the design differences. However, the objective of converting costs into constant dollars with a construction cost index (such as the Handy-Whitman index) is to remove the inflation aspects of cost increases and to provide a more nearly common basis for comparison. The increased costs resulting from a stretched out construction period should be accounted for separately, as discussed in the following section.

The three time variables discussed above produce different results, as they produce shifts in the relative positions (along the time scale) of datum points for units having differing lengths of construction duration. An example of the variations in regression coefficients resulting from these three different time variables may be seen in the regression results shown in Tables 3.5.1 through 3.5.3. These are the regression results for cost, without IDC, for 31 nuclear units. The statistical significance is poor for each of these regressions, becoming progressively worse with the shift toward the date of completion of construction.

The time variable for the regression equation in Table 3.5.1 is T65 (year of construction start - 1965). The time variable in the regression shown in Table 3.5.2 is T67 (mid-point of construction period - 1967), and the time variable for the regression results shown in Table 3.5.3 is T70 (the year of completion of construction - 1970). The reference year is

Table 3.5.1. Regression Analysis for Total Cost (1984 $), Without IDC, for Nuclear Units with Year of Construction Start as the Time Variable.

DEP VARIABLE: LCI84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.10903790	0.27725948	3.406	0.0229
ERROR	26	2.11637873	0.08139918		
C TOTAL	30	3.22541663			

ROOT MSE	0.2853054	R-SQUARE	0.3438
DEP MEAN	14.23126	ADJ R-SQ	0.2429
C.V.	2.00478		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	8.24631222	3.51540070	2.346	0.0269
LMW	1	0.78685526	0.50561192	1.556	0.1317
FIRST	1	0.25459083	0.10413228	2.445	0.0216
SOUTH	1	-0.11597541	0.10466053	-1.108	0.2780
T65	1	0.04422672	0.02502655	1.767	0.0889

Table 3.5.2. Regression Analysis for Cost (1984 $), Without IDC, for Nuclear Units with Mid-Point of Construction Period as the Time Variable.

DEP VARIABLE: LCI84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.03453906	0.25863477	3.069	0.0339
ERROR	26	2.19087757	0.08426452		
C TOTAL	30	3.22541663			

ROOT MSE	0.2902835	R-SQUARE	0.3207
DEP MEAN	14.23126	ADJ R-SQ	0.2162
C.V.	2.03976		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	9.24800356	3.69133039	2.505	0.0188
LMW	1	0.62977537	0.54216221	1.162	0.2560
FIRST	1	0.27263650	0.10762033	2.533	0.0177
SOUTH	1	-0.12773764	0.10916474	-1.170	0.2526
T67	1	0.03972880	0.02720470	1.460	0.1562

Table 3.5.3. Regression Analysis for Cost (1984 $), Without IDC, for Nuclear Units With Year of End of Construction as the Time Variable.

DEP VARIABLE: LC184

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.91364462	0.22841116	2.569	0.0617
ERROR	26	2.31177201	0.08891431		
C TOTAL	30	3.22541663			

ROOT MSE	0.298185	R-SQUARE	0.2833
DEP MEAN	14.23126	ADJ R-SQ	0.1730
C.V.	2.095282		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	8.97801770	3.90822811	2.297	0.0299
LMW	1	0.70109988	0.57666594	1.216	0.2350
FIRST	1	0.26518883	0.11185552	2.371	0.0254
SOUTH	1	-0.10987173	0.11258324	-0.976	0.3381
T70	1	0.01782813	0.02192058	0.813	0.4234

arbitrary, since the regression results are not affected by the specification of a reference year in this model, except in the value of the intercept. The reference years were selected primarily for convenience in assigning names to these three time variables.

The indicated values of the scaling exponent, for these three time variable designations, are 0.79 for T65, 0.63 for T67, and 0.70 for T70. The coefficients for the time variables indicate annual percent increases in cost of 4.4% for T65, 4.0% for T67, and 1.8% for T70.

For other analyses using these three time variables the values of the scaling exponent decreased with the substitution of T67 for T65, and with the substitution of T70 for T67. The annual percent change in cost also decreased with these successive substitutions.

The three regression equations chosen for the discussion here were selected because of the reversal in the direction of the changing value of the scaling exponent. This is an interesting result which may possibly be qualitatively explained with the aid of a three-dimensional representation of a plane defined by the cost estimating equation.

In the regression equations, the cost is expressed as a function of two continuous variables. For any set of values for the dummy variables, the value of ln COST (LCI84 in the regression equations) is a value on a plane determined by a three-dimensional plot with ln COST as the vertical axis, and with ln CAP (LMW in the regression equations) and Time as the axes in the horizontal plane. For any other set of values of dummy variables, the equations define parallel planes. A representation of such a plot is shown in Figure 3.5.1, but ln C/KW is used to simplify the presentation.

Three hypothetical points, representing three units (datum points) with different capacities and different time of construction start, are shown in the figure as points A, B, and C. These three points define the plane in the figure, and the slope along a line parallel to the ln C/KW - ln CAP plane is negative, corresponding to the scaling exponent minus one, or (P-1). The slope along a line parallel to the ln C/KW-Time plane is positive.

If these three points were plotted with T67 as the time variable, and each of the three has the same construction duration, the three points would be in the same position relative to each other and the time scale in

Figure 3.5.1. Plot of ln C/KW vs. time and ln CAP as a hypothetical model for illustrating effects of different choices of time variable.

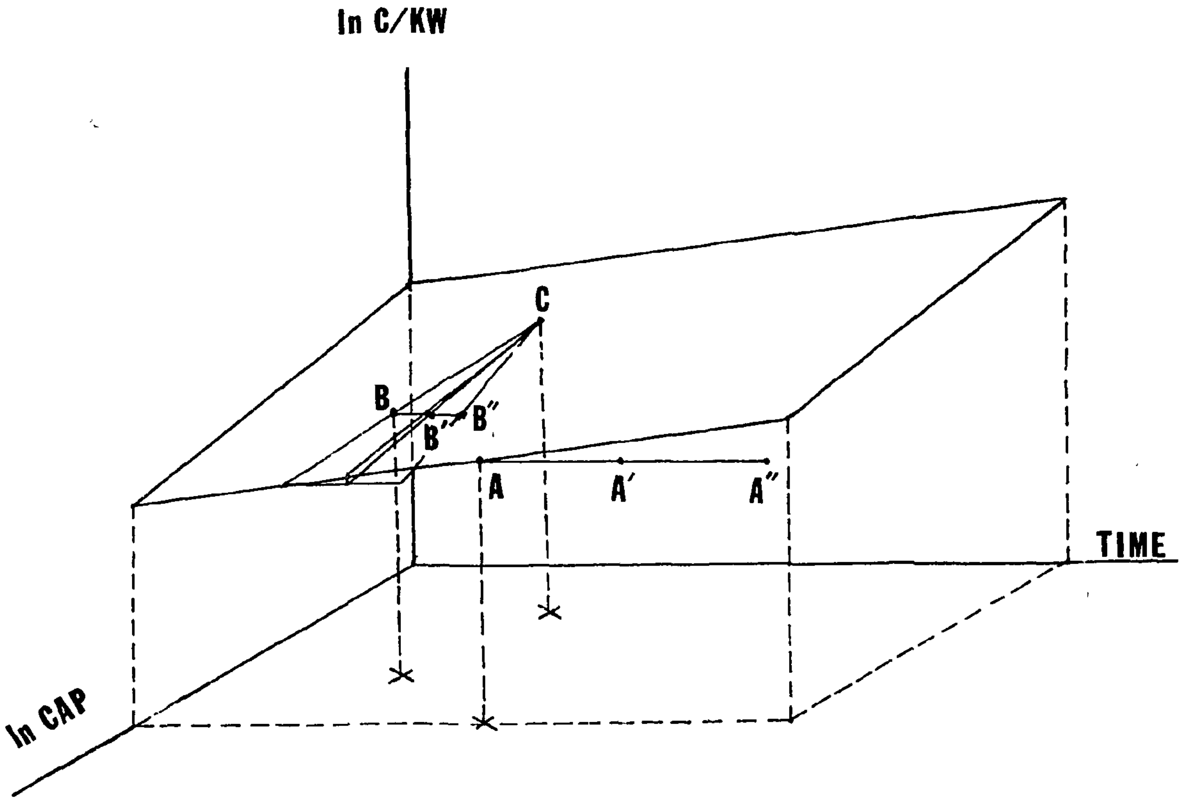


Figure 3.5.1 could simply be renumbered. No other changes in the figure would be necessary.

If, however, points B and C have the same value for construction duration but A has a longer duration, point A would move (by translation parallel to the Time-axis) to a new location such as the one designated as A' on the renumbered scale. The point A' is below the original plane, and a new plane defined by the points A', B and C could be formed by rotating the original plane about the line defined by points B and C. The new plane would have a steeper slope of a line in a plane parallel to the ln COST - ln CAP plane than the slope in the original plane, indicating an improved value of the scaling exponent. In the new plane, the slope of a line parallel to the ln C/KW - Time plane would not be as steep as the line in the original plane.

With an additional stipulation, an explanation can be offered for the subsequent decrease in absolute value of the the slope, representing (P - 1), when T70 becomes the time variable. If point B represents a unit with a longer duration of construction than the unit represented by point C, but it is assumed again that point C remains in the same position as the time shift takes place and the time scale is renumbered, then point B could move to a point B' (as point A moves to point A') with the shift in time scale from T65 to T67. Thus, the line about which the plane rotated has itself rotated during the shift, creating a wobble of the plane. Note that B' has been placed on a line which passes through C and is parallel to the ln C/KW - ln CAP plane, and any tilting of the plane about the line B'-C would result in a change only in the annual percent change in cost.

The next step is the time shift from T67 to T70. Again, assuming that point C remains at the same position on the plot as the time-scale is again renumbered and that the other two points move distances equal to the respective distances moved by those points during the first time shift, a rotation of the plane about the moving line connecting point C and the original point B as it now moves from point B' to B" results in a tilt of the plane to decrease the magnitude of the slope of a line parallel to the ln C/KW - ln CAP plane. At the same time, the slope of a line parallel to the ln C/KW - Time plane has again decreased.

Where the data for a regression analysis represent a large number of points, most of which do not lie in the plane, the simple geometric model discussed above is inadequate in explaining the shifting values of coefficients in the regression equation. However, an analogous conceptual model may be helpful in seeking an explanation for other seemingly mysterious shifting values of regression coefficients, which may be explained in some cases by simple geometric principles.

3.6 DURATION AS A VARIABLE

In a regression analysis of costs of nuclear power plants, Zimmerman (6) uses as "independent" variables two terms which together represent the project duration. He uses the estimated time from the announcement of a project to the anticipated date of operation as one independent variable, and the difference between the actual and anticipated time of operation as another independent variable. With LETIME and LUTIME designated as the natural logarithms of these variables, partial results are:

$$\ln C/KW = -0.17\ (\ln SIZE) + 1.01\ (LETIME) + 0.12\ (LUTIME) + \text{other terms} \tag{3.6.1}$$

where SIZE is capacity (in MW).

The solution to the cost ratio of two plants A and B is:

$$C_A/C_B = (SIZE_A/SIZE_B)^{0.83} \times (ETIME_A/ETIME_B)^{1.01} \times (UTIME_A/UTIME_B)^{0.12} \tag{3.6.2}$$

Although some planning estimates of project construction do not indicate a relation between project size (capacity) and duration, most analyses based on historical data show a size-duration relationship. Komanoff (7), for example, obtained a relationship for nuclear plants showing that the duration increases as the capacity to the 0.358 power. Thus, doubling the capacity would indicate a duration of 1.28 times that of the smaller of the two units. If a more conservative value of 1.10 is used as the ratio in each of the time terms in Eq. 3.6.2, the cost ratio for doubling the capacity of a unit becomes 1.98; setting this equal to 2.0 raised to the power P, the scaling exponent P becomes 0.98.

The CRA-EEI data were subjected to a regression analysis with construction duration included in the cost equation as an additional "independent" variable, approximating the Zimmerman model, to compare the results with those of the previously discussed model in which duration was not included in the model. Entering duration into the cost equation creates a problem of simultaneity bias, since duration and cost are jointly determined by the independent variables.

If one of two variables, which may be determined simultaneously from separate regressions on the same set of explanatory variables, is additionally included as a possible explanatory variable in a regression for the other of the two, the result is simultaneity bias.

A regression was carried out to estimate the duration as a function of the independent variables. Then the duration expression was substituted into the cost equation to determine the scaling exponent, which is identically equal to the scaling exponent determined by the regression equation in which duration was not included as an independent variable.

The regressions and calculations described above were performed for coal-fired units and for nuclear units. The time variable was taken as the construction start date. The results are summarized in Table 3.6.1 to

Table 3.6.1. Regression Results Illustrating the Relation Between the Scaling Exponent and the Coefficient of (ln CAP) in a Regression With Duration Included as an Independent Variable.

	Scaling Exponent	Equation	Coef. of (ln CAP)	Coef. of (ln DUR)
Coal-fired Units	0.894	Cost	0.843	0.193
		Duration	0.263	
Nuclear Units	0.950	Cost	0.756	0.607
		Duration	0.320	

illustrate the differences between the coefficients of the logarithm of capacity and the scaling exponents. The complete regression results are shown in Tables 3.6.2 through 3.6.7.

Table 3.6.2. Regression Analysis for Total Cost (1984 $) for Nuclear Units, With the Natural Logarithm of (Duration (in Months) of Construction Divided by 100) Included as an Independent Variable.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	7	28.39059753	4.05579965	71.338	0.0001
ERROR	81	4.60509937	0.05685308		
C TOTAL	88	32.99569690			

ROOT MSE	0.2384388	R-SQUARE	0.8604
DEP MEAN	14.03677	ADJ R-SQ	0.8484
C.V.	1.698673		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	8.12669390	0.92885670	8.749	0.0001
LMW	1	0.75561964	0.13593525	5.559	0.0001
FIRST	1	0.22798304	0.05461525	4.174	0.0001
SOUTH	1	-0.23461459	0.05223195	-4.492	0.0001
T65	1	0.14358856	0.02406960	5.966	0.0001
E79	1	0.13265483	0.22125162	0.600	0.5505
E79T65	1	-0.04591527	0.02937769	-1.563	0.1220
LD100	1	0.60700237	0.13596134	4.465	0.0001

Table 3.6.3. Regression Analysis for Natural Logarithm of Duration (in Months) of Construction for Nuclear Units.

DEP VARIABLE: LDUR

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	6	9.90137580	1.65022930	43.926	0.0001
ERROR	83	3.11815306	0.03756811		
C TOTAL	89	13.01952886			

ROOT MSE	0.1938249	R-SQUARE	0.7605
DEP MEAN	4.508543	ADJ R-SQ	0.7432
C.V.	4.299059		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	2.18210613	0.70665940	3.088	0.0027
LMW	1	0.31999801	0.10475577	3.055	0.0030
FIRST	1	-0.11808627	0.04231509	-2.791	0.0065
SOUTH	1	0.005339355	0.04204795	0.127	0.8993
T65	1	-0.01191290	0.01951989	-0.610	0.5433
E79	1	0.84842003	0.15314617	5.540	0.0001
E79T65	1	-0.02826457	0.02365343	-1.195	0.2355

Table 3.6.4. Regression Analysis for Total Cost (1984 $) for Nuclear Units, With Same Set of Independent Variables Employed in Regression for Duration of Construction.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	6	27.25740445	4.54290074	64.918	0.0001
ERROR	82	5.73829245	0.06997918		
C TOTAL	88	32.99569690			

ROOT MSE	0.2645358	R-SQUARE	0.8261
DEP MEAN	14.03677	ADJ R-SQ	0.8134
C.V.	1.884592		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.67802167	0.96559309	6.916	0.0001
LMW	1	0.94611246	0.14319127	6.607	0.0001
FIRST	1	0.15954955	0.05815746	2.743	0.0075
SOUTH	1	-0.22765351	0.05792287	-3.930	0.0002
T65	1	0.13626200	0.02664186	5.115	0.0001
E79	1	0.65015693	0.20908378	3.110	0.0026
E79T65	1	-0.06353671	0.03229755	-1.967	0.0525

Table 3.6.5. Regression Analysis for Total Cost (1984 $) for Coal-Fired Units, With the Natural Logarithm of (Duration, in Months, Divided by 60) Included as an Independent Variable.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	11	21.39346645	1.94486059	31.964	0.0001
ERROR	96	5.84107131	0.06084449		
C TOTAL	107	27.23453776			

ROOT MSE	0.2466668	R-SQUARE	0.7855
DEP MEAN	12.8948	ADJ R-SQ	0.7610
C.V.	1.912917		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	7.15936573	0.48034110	14.905	0.0001
LMW	1	0.84346572	0.06529676	12.917	0.0001
FIRST	1	0.33170814	0.05050013	6.568	0.0001
SOUTH	1	-0.10295964	0.05049187	-2.039	0.0442
DFGD	1	0.22914591	0.46127421	0.497	0.6205
T65	1	0.02616763	0.02108809	1.241	0.2177
FT65	1	-0.009480477	0.03937813	-0.241	0.8103
S79	1	0.18444824	3.85053442	0.048	0.9619
S79T65	1	-0.01242295	0.26644852	-0.047	0.9629
FS79	1	-1.04381754	4.01931470	-0.260	0.7957
FS79T65	1	0.08381963	0.27746139	0.302	0.7632
LD60	1	0.19342263	0.09152621	2.113	0.0372

Table 3.6.6. Regression Analysis for Natural Logarithm of Duration (in Months) of Construction for Coal-Fired Units.

DEP VARIABLE: LDUR

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	10	2.74957079	0.27495708	3.672	0.0003
ERROR	97	7.26323829	0.07487875		
C TOTAL	107	10.01280908			

ROOT MSE	0.2736398	R-SQUARE	0.2746
DEP MEAN	4.033213	ADJ R-SQ	0.1998
C.V.	6.78466		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	3.23297527	0.52564021	6.151	0.0001
LMW	1	0.26345745	0.06731678	3.914	0.0002
FIRST	1	-0.01702924	0.05599564	-0.304	0.7617
SOUTH	1	-0.05779052	0.05570498	-1.037	0.3021
DFGD	1	-0.18346901	0.51137543	-0.359	0.7205
T65	1	-0.06682227	0.02238861	-2.985	0.0036
FT65	1	0.01420737	0.04366031	0.325	0.7456
S79	1	-2.50441934	4.26401545	-0.587	0.5583
S79T65	1	0.17862255	0.29502777	0.605	0.5463
FS79	1	2.65892584	4.45064665	0.597	0.5516
FS79T65	1	-0.17430788	0.30729259	-0.567	0.5719

Table 3.6.7. Regression Analysis for Total Cost (1984 $) for Coal-Fired Units, with Same Set of Independent Variables Employed in Regression for Duration of Construction.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	10	21.12173189	2.11217319	33.517	0.0001
ERROR	97	6.11280587	0.06301862		
C TOTAL	107	27.23453776			

ROOT MSE	0.2510351	R-SQUARE	0.7755
DEP MEAN	12.8948	ADJ R-SQ	0.7524
C.V.	1.946793		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.99275742	0.48221835	14.501	0.0001
LMW	1	0.89442436	0.06175590	14.483	0.0001
FIRST	1	0.32841430	0.05136997	6.393	0.0001
SOUTH	1	-0.11413764	0.05110332	-2.233	0.0278
DFGD	1	0.19365885	0.46913195	0.413	0.6807
T65	1	0.01324269	0.02053914	0.645	0.5206
FT65	1	-0.006732450	0.04005363	-0.168	0.8669
S79	1	-0.29996314	3.91177553	-0.077	0.9390
S79T65	1	0.02212669	0.27065625	0.082	0.9350
FS79	1	-0.52952110	4.08298958	-0.130	0.8971
FS79T65	1	0.05010454	0.28190790	0.178	0.8593

In the following example solution, the regression results for nuclear units are used.

$$\ln DUR = 0.320(\ln CAP) + a, \text{ where } \underline{a} \text{ includes all other terms} \quad (3.6.3)$$

$$DUR = CAP^{0.32} (e^{a}) \quad (3.6.4)$$

$$\ln COST = 0.756(\ln CAP) + 0.607(\ln DUR) + b, \text{ where } \underline{b} \text{ includes all other terms} \quad (3.6.5)$$

$$COST = (CAP)^{0.756} (DUR)^{0.607} (e^{b}) \quad (3.6.6)$$

The ratio of the costs of two plants, A and B, is

$$\frac{COST_A}{COST_B} = \left(\frac{CAP_A}{CAP_B}\right)^{0.756} \left(\frac{DUR_A}{DUR_B}\right)^{0.607}$$

$$= \left(\frac{CAP_A}{CAP_B}\right)^{0.756} \left(\frac{CAP_A}{CAP_B}\right)^{0.32(0.607)}$$

$$= \left(\frac{CAP_A}{CAP_B}\right)^{0.950} \quad (3.6.7)$$

The scaling exponent is 0.950 rather than the value of 0.756 which is the regression coefficient of ln CAP in the cost regression which included the duration as an independent variable.

Thus, a regression analysis which includes duration as an "independent" variable produces a coefficient of (ln CAP) which cannot be interpreted as the scaling exponent. It should also be noted that the coefficients of other terms in the regression equations can be substantially different when duration is included as an independent variable. For example, for nuclear units with the construction start date used as the time variable, the coefficient of the dummy variable for a first unit is 0.156 compared with 0.228 in the regression with duration included as a variable. With a substitution of ln DUR into the cost equation, the resulting equation for cost (with duration eliminated as an "independent" variable) has coefficients which are identical to those in the cost regression which did not include duration as in independent variable.

It should be pointed out that the primary purpose of Zimmerman's model was to investigate the effect of learning (construction experience, etc.)

on the cost of nuclear plant construction, and his model may very well have been quite suitable for this purpose.

In a regression analysis of capital Cost/kW for nuclear plants by Perl (8), the model employed 5 continuous independent variables, including the midpoint of the construction period for the plant (rather than a unit) and the natural logarithm of capacity. The coefficient of the natural logarithm of capacity was -0.5063, and some reviewers have referred to this value as the scaling exponent minus one, although the author does not suggest in his paper that 0.49 (which is 1-0.5063) should be interpreted as a scaling exponent.

Another continuous variable was the natural logarithm of licensing time (the time from application for to receipt of construction permit), and another is the natural logarithm of the number of nuclear units built by the architect-engineer (A/E). The latter two variables are related to time, as is the capacity of the units. A regression analysis of the CRA-EEI data for capacity as a function of time, presented in Section 3.4, indicates an increase in capacity from 790 to 1108 MW during the time period from 1967 to 1976. Budwani (9) indicates the average time required to obtain the construction permit (CP) went from about 10 months to about 30 months (based on an estimated smooth curve through his data) during the same period.

The ratio of average capacities at the end and beginning of this period is ostensibly only a time relationship, as is the ratio of average CP times at the end and beginning of the period. As such, these should ideally be kept separate from each other in the statistical analysis, but since the construction permit times will vary (randomly or otherwise) with capacity for any year, it would appear that only a stroke of luck would prevent some interdependency between these variables in a regression analysis.

In the absence of any information as to how much (if any) of the CP time would be picked up in the capacity, an assumed ratio of CP times may be substituted into Perl's equation to establish a speculative estimate of the effect which it might have.

If a time-independent ratio of 2 for the CP times is assumed for the ratio of capacities of 1108 and 790 MW, the ratios may be set equal to each other and substituted into Perl's equation to eliminate the CP time.

Converting the equation to total cost, the result is

$$\frac{C_A}{C_B} = \left(\frac{CAP_A}{CAP_B}\right)^{0.4937} \left(\frac{CP_A}{CP_B}\right)^{0.1143}$$

$$= \left(\frac{1108}{790}\right)^{0.4937} (2)^{0.1143}$$

$$= 1.279 \qquad (3.6.8)$$

Setting the cost ratio equal to the capacity ratio to a power q, and solving for q

$$1.279 = \left(\frac{CAP_A}{CAP_B}\right)^{q}$$

$$= \left(\frac{1108}{490}\right)^{q} \qquad (3.6.9)$$

$$q = (\ln 1.279)/(\ln 1108/490)$$

$$= 0.73 \qquad (3.6.10)$$

If the CP time-capacity relationship assumed above were the only interdependent relationship, this would suggest that the value of 0.73 might be interpreted as a scaling exponent, based on the CP time-capacity ratio assumed above without mathematical foundation. However, the A/E experience would very likely be picked up in the capacity in a similar manner. If it is again assumed that the time-independent A/E experience ratio picked up by the capacity ratio used above is 2, the result is

$$\frac{C_A}{C_B} = \left(\frac{CAP_A}{CAP_B}\right)^{0.4937} \left(\frac{CP_A}{CP_B}\right)^{0.1143} \left(\frac{A/E_A}{A/E_B}\right)^{-0.0544}$$

$$= \left(\frac{1108}{790}\right)^{0.4937} (2)^{0.1143} (2)^{-0.0544}$$

$$= 1.232 \qquad (3.6.11)$$

Setting this cost ratio equal to the capacity ratio to a power r, and solving for r

$$1.232 = \left(\frac{1108}{490}\right)^r \qquad (3.6.12)$$

$$r = 0.62 \qquad (3.6.13)$$

Based on the assumed interrelationships above, which are without mathematical foundation and do not even fall into the classification of being estimates, the value calculated above might be considered a speculative estimate of a scaling exponent. More than anything else, however, this exercise may suggest further exploration of the model used in the regression analysis, particularly as to its relation to economy of scale. Neither construction permit time nor A/E experience was obtained for the CRA-EEI data base, and thus there was no opportunity to compare models in a manner analogous to the developments presented in Eq. 3.6.3 through 3.6.7.

While the problem of simultaneity bias does not preclude the possibility of arriving at the scaling exponent by additional calculations, as an alternative to simultaneous solution of the equations, a preferred method of estimating the effects of duration variations on the cost is to use the residual of duration regressed on the same variables included in the cost equation. This regression gives identical coefficients (when data sets are identical) of the variables as those in the cost equation in which duration was not included as a variable, but has the added term which may be used to determine the effect on cost of a duration variation from the "normal" duration determined from the duration regression. The regression results for the residual of duration are shown in Tables 3.6.8 and 3.6.9.

As an example, the effect on cost can be determined for a 175-month construction period on a second nuclear unit located on a site in the South with construction started in 1972, a capacity of 1100 MW, with construction completed after TMI. The cost of such a unit, with a normal construction period, is determined from Table 3.6.8.

Table 3.6.8. Regression Analysis for Total Cost (1984 $) for Nuclear Units, With the Residual of Log Duration Included as a Variable.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	7	28.39059753	4.05579965	71.338	0.0001
ERROR	81	4.60509937	0.05685308		
C TOTAL	88	32.99569690			

ROOT MSE	0.2384388	R-SQUARE	0.8604
DEP MEAN	14.03677	ADJ R-SQ	0.8484
C.V.	1.598673		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|	VARIABLE LABEL
INTERCEP	1	6.65588827	0.87034968	7.647	0.0001	INTERCEPT
LMW	1	0.94985919	0.12906792	7.359	0.0001	
FIRST	1	0.15630439	0.05242516	2.981	0.0038	
SOUTH	1	-0.23137359	0.05221532	-4.431	0.0001	
T65	1	0.13635739	0.02401360	5.678	0.0001	
E79	1	0.64764780	0.18845812	3.437	0.0009	
E79T65	1	-0.06307193	0.02911152	-2.167	0.0332	
RLDUR	1	0.60700237	0.13596134	4.465	0.0001	RESIDUALS

Table 3.6.9. Regression Analysis for Total Cost (1984 $) for Coal-Fired Units, With the Residual of Log Duration Included as a Variable.

DEP VARIABLE: LC84

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	11	21.39346645	1.94486059	31.964	0.0001
ERROR	96	5.84107131	0.06084449		
C TOTAL	107	27.23453776			

ROOT MSE	0.2466668	R-SQUARE	0.7855
DEP MEAN	12.8948	ADJ R-SQ	0.7610
C.V.	1.912917		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|	VARIABLE LABEL
INTERCEP	1	6.99275742	0.47382715	14.758	0.0001	INTERCEPT
LMW	1	0.89442436	0.06068127	14.740	0.0001	
FIRST	1	0.32841430	0.05047607	6.506	0.0001	
SOUTH	1	-0.11413764	0.05021406	-2.273	0.0253	
DFGD	1	0.19365885	0.46096846	0.420	0.6753	
T65	1	0.01324269	0.02018173	0.656	0.5133	
FT65	1	-0.006732450	0.03935665	-0.171	0.8645	
S79	1	-0.29996314	3.84370570	-0.078	0.9380	
S79T65	1	0.02212669	0.26594649	0.083	0.9339	
FS79	1	-0.52952110	4.01194042	-0.132	0.8953	
FS79T65	1	0.05010454	0.27700235	0.181	0.8568	
RLDUR	1	0.19342263	0.09152621	2.113	0.0372	RESIDUALS

$$\ln C = 6.6559 + 0.9499(\ln CAP) + 0.1563(FIRST) - 0.2314(SOUTH) + 0.1364(T65) + 0.6477(E79) - 0.0631(E79)(T65)$$

$$= 6.6559 + 0.9499(\ln 1100) + 0.1563(0) - 0.2314(1) + 0.1364(72-65) + 0.6477(1) - 0.0631(1)(72-65)$$

$$= 14.2375 \quad (3.6.14)$$

$$C = 1{,}525{,}011 \text{ (Note: Cost} = \$1000(C) = \$1.525 \text{ billion)} \quad (3.6.15)$$

The normal construction period is next calculated from Table 3.6.3.

$$\ln DUR = 2.1821 + 0.3200(\ln CAP) - 0.1181(FIRST) - 0.0053(SOUTH) - 0.0119(T65) + 0.8484(E79) - 0.0283(E79)(T65)$$

$$= 2.1821 + 0.3200(\ln 1100) - 0.1181(0) - 0.0053(1) -0.0119(72-65) + 0.8484(1) - 0.0283(1)(72-65)$$

$$= 4.9848 \quad (3.6.16)$$

$$DUR = 146.2 \text{ months} \quad (3.6.17)$$

Now the effect of the difference between the 175-month construction period and a normal construction period of 146.2 months is accounted for by the term for the residual of duration - the last term in the equation in Table 3.6.8.

$$\ln (\text{ADJUSTED COST}) = \ln C + 0.6070(\ln 175/146.2)$$

$$= 14.2375 + 0.1091$$

$$= 14.3466 \quad (3.6.18)$$

$$\text{ADJUSTED COST} = 1{,}700{,}860 \quad (3.6.19)$$

The cost of this plant with the extended or stretched out duration, is 1.115 times the cost of a plant identical in all respects but with a normal construction duration of 146.2 months. The 11.5 percent increase can be determined more directly by observing that

$$\ln(\text{ADJUSTED COST}) - \ln C = 0.607 \ln(\text{DURATION RATIO}) \tag{3.6.20}$$

$$\ln(\text{ADJUSTED COST}/C) = \ln(\text{DURATION RATIO})^{0.607} \tag{3.6.21}$$

$$\begin{aligned} \text{ADJUSTED COST}/C &= (\text{DURATION RATIO})^{0.607} \\ &= (175/146.2)^{0.607} \\ &= 1.115 \end{aligned} \tag{3.6.22}$$

3.7 CROSS-SECTIONAL ANALYSIS

In the previous sections it has been shown that analytic results of estimating scaling factors are highly influenced by the model specification selected and how the time-control variable is defined. To investigate the possibility that multicollinearity between unit capacity and unit vintage biases the scaling estimates obtained from pooled cross-section/time-series models, two model specifications were developed to avoid some of the difficulties encountered when using cross-section/time series analysis. The first involved a strictly cross-section analysis of the scaling factor separately by pairs of years of construction start and capacity range for both coal and LWR units, the capacity range being treated in the next section.

The second specification involved two steps: in step (1) a pooled cross-section/time series model was estimated and the coefficients were used to "treat" the cost of each generating unit for effects of unit order, South or non-South, vintage and FGD (for coal units) or post-TMI completion (for LWR units), after controlling on capacity. In step (2) these cost data were then regressed on capacity separately by year of start date and capacity range (the latter in the next section). This second specification was made to stabilize the effects of the independent variables, since they would be expected to fluctuate by year of start and capacity category in the strictly cross-section models due to the small number of observations.

By inspecting the coefficients of ln CAP in the cross-sectional analysis of both untreated data and the treated data, it should be possible to observe directly whether or not there is a time or capacity range trend in the scaling factor. It is concluded that the subsequent cross-sectional analysis offers the best and most direct observation of the trend, but not necessarily magnitude, of scale economies at different points in time and among different capacity categories.

Equation 3.7.1 shows the specification of the first regression model that was used to analyze the untreated data cross-sectionally for coal units. Note that the equation is similar to Equation 3.1.12 except dummy variables were used for each year of construction start rather than a continuous time variable.

$$\ln (COST/KW) = a + b_1(\ln CAP) + b_2(unit) + b_3(South) + b_4(FGD) + \sum_{i=1}^{8} d_i(DUM_i) + e \qquad (3.7.1)$$

where all variables are as defined in Equation 3.1.12 except the following eight time dummy variables, representing year of construction start, replace T65, a continuous time variable:

DUM_1 = 1 if 1974, otherwise 0;

DUM_2 = 1 if 1975, otherwise 0;

DUM_3 = 1 if 1976, otherwise 0;

DUM_4 = 1 if 1977, otherwise 0;

DUM_5 = 1 if 1978, otherwise 0;

DUM_6 = 1 if 1979, otherwise 0;

DUM_7 = 1 if 1980, otherwise 0;

DUM_8 = 1 if 1981, otherwise 0;

Intercept = 1973.

Tables 3.7.1 through 3.7.4 show the results for the separate regressions by time of construction start. These data reveal little evidence that the scaling coefficient has a time trend. It can be seen in the tables that the coefficients of ln CAP ranged only from -.05 to -.10 and did not consistently decrease or increase with time of start. None were significantly different from zero in any of the cross-sections.

Equation 3.7.1 estimated on the total data for all years yielded the coefficients shown in Table 3.7.5. These coefficients were used to treat the data in the second model specification discussed earlier. They adjusted the cost data of coal units for the estimated effects of all variables in the equation except ln CAP as the first step. In the second step the ln of treated cost per KW was regressed on ln CAP separately by time of start date. The results are shown in Tables 3.7.6 through 3.7.9.

It can be seen from the tables that there is apparently no time trend in the coefficient of ln CAP when analyzing the treated data. This confirms the results of the preceding cross-sectional regressions. The most favorable scaling was found in the 1977-1978 data and the least in that of 1973-1974.

Equation 3.7.1 was also estimated for plant costs without IDC and the regression results and tables comparable to Tables 3.7.1 through 3.7.9 but without IDC are shown in Appendix B. They parallel the analysis of costs with IDC, supporting the conclusion that there is little evidence of economy of scale in coal powerplant construction.

A similar analysis was made for LWR units. Equation 3.7.2 shows the specification used to analyze the untreated LWR powerplant cost data cross-sectionally by time of construction start. Note that this equation is similar to Equation 3.1.11 except a dummy variable was used for each year of construction start rather than a continuous variable. Since the data by year of start are too sparse for meaningful analysis, start years were paired.

$$\ln(\text{COST/KW}) = a + b_1(\ln \text{CAP}) + b_2(\text{unit}) + b_3(\text{SOUTH}) + b_4(\text{E79}) + \sum_{i=1}^{9} d_i(\text{DUM}_i) + e \qquad (3.7.2)$$

Table 3.7.1. Cross-Section Regression for Coal Units: 1973-1974.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.94806995	0.23701749	3.154	0.0511
ERROR	13	0.97688608	0.07514508		
C TOTAL	17	1.92495603			

ROOT MSE	0.274126	R-SQUARE	0.4925
DEP MEAN	6.528866	ADJ R-SQ	0.3364
C.V.	4.198677		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.72673607	1.52651024	4.407	0.0007
LMW	1	-0.04953152	0.23732953	-0.209	0.8379
FIRST	1	0.46126731	0.17560107	2.627	0.0209
SOUTH	1	-0.09223081	0.16699009	-0.552	0.5901
DFGD	1	0.07909527	0.20143482	0.393	0.7009

Table 3.7.2. Cross-Section Regression for Coal Units: 1975-1976.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.61078300	0.15269575	2.556	0.0766
ERROR	17	1.01567741	0.05974573		
C TOTAL	21	1.62646040			

ROOT MSE	0.2444294	R-SQUARE	0.3755
DEP MEAN	6.64925	ADJ R-SQ	0.2286
C.V.	3.676044		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.78778497	0.91087137	7.452	0.0001
LMW	1	-0.05560251	0.14616596	-0.380	0.7084
FIRST	1	0.30677718	0.11083594	2.768	0.0132
SOUTH	1	0.06038000	0.11119808	0.543	0.5942
DFGD	1	0.14476995	0.11015507	1.314	0.2062

Table 3.7.3. Cross-Section Regression for Coal Units: 1977-1978.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.90938882	0.47734720	7.065	0.0003
ERROR	33	2.22957255	0.06756280		
C TOTAL	37	4.13896137			

ROOT MSE	0.2599285	R-SQUARE	0.4613
DEP MEAN	6.624646	ADJ R-SQ	0.3960
C.V.	3.923658		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	7.25024645	0.65152261	11.128	0.0001
LMW	1	-0.10331500	0.10466992	-0.987	0.3308
FIRST	1	0.29271837	0.08588809	3.408	0.0017
SOUTH	1	-0.26310952	0.09344301	-2.816	0.0081
DFGD	1	0.03512225	0.10531436	0.333	0.7409

Table 3.7.4. Cross-Section Regression for Coal Units: 1979-1980.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.30065603	0.32516401	4.805	0.0076
ERROR	19	1.28585064	0.06767635		
C TOTAL	23	2.58650667			

ROOT MSE	0.2601468	R-SQUARE	0.5029
DEP MEAN	6.991136	ADJ R-SQ	0.3982
C.V.	3.721095		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.93251964	0.80337373	8.629	0.0001
LMW	1	-0.06755328	0.13189408	-0.512	0.6144
FIRST	1	0.36780200	0.11715892	3.139	0.0054
SOUTH	1	-0.07842707	0.11045729	-0.710	0.4863
DFGD	1	0.33918369	0.11875461	2.856	0.0101

Table 3.7.5. Cross-Section/Time-Series Pooled Regression for Coal Units: 1973-1981.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	12	8.06286214	0.67190518	10.656	0.0001
ERROR	95	5.99004878	0.06305315		
C TOTAL	107	14.05291092			

ROOT MSE	0.2511039	R-SQUARE	0.5738
DEP MEAN	6.718009	ADJ R-SQ	0.5199
C.V.	3.737772		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.74087139	0.44540221	15.134	0.0001
LMW	1	-0.05488913	0.06409764	-0.856	0.3940
FIRST	1	0.32036011	0.05108162	6.272	0.0001
SOUTH	1	-0.11422172	0.05339836	-2.139	0.0350
DFGD	1	0.17203467	0.05749569	2.992	0.0035
D74	1	0.04417421	0.16514784	0.267	0.7897
D75	1	0.15703279	0.16741915	0.938	0.3506
D76	1	0.03195438	0.17565687	0.182	0.8560
D77	1	-0.000781300	0.16630973	-0.005	0.9963
D78	1	0.13384050	0.15957875	0.839	0.4037
D79	1	0.21994709	0.16800039	1.309	0.1936
D80	1	0.37927294	0.18398006	2.061	0.0420
D81	1	0.39275171	0.18769960	2.092	0.0391

Table 3.7.6. Cross-Section Regression of Treated Coal Unit Data: 1973-1974.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.009600580	0.009600580	0.150	0.7041
ERROR	16	1.02740692	0.06421293		
C TOTAL	17	1.03700750			

ROOT MSE	0.2534027	R-SQUARE	0.0093
DEP MEAN	-0.350731	ADJ R-SQ	-0.0527
C.V.	-72.2499		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-0.80540191	1.17738692	-0.684	0.5037
LMW	1	0.07115564	0.18402288	0.387	0.7041

Table 3.7.7. Cross-Section Regression of Treated Coal Unit Data: 1975-1976.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.02121277	0.02121277	0.385	0.5418
ERROR	20	1.10098090	0.05504904		
C TOTAL	21	1.12219367			

ROOT MSE	0.2346253	R-SQUARE	0.0189
DEP MEAN	-0.332439	ADJ R-SQ	-0.0302
C.V.	-70.577		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	0.14255951	0.76682156	0.186	0.8544
LMW	1	-0.07842719	0.12634059	-0.621	0.5418

Table 3.7.8. Cross-Section Regression of Treated Coal Unit Data: 1977-1978.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.06163019	0.06163019	0.965	0.3325
ERROR	36	2.29966475	0.06387958		
C TOTAL	37	2.36129494			

ROOT MSE	0.2527441	R-SQUARE	0.0261
DEP MEAN	-0.337373	ADJ R-SQ	-0.0010
C.V.	-74.9153		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	0.23896857	0.58819581	0.406	0.6869
LMW	1	-0.09376827	0.09546412	-0.982	0.3325

Table 3.7.9. Cross-Section Regression of Treated Coal Unit Data: 1979-1980.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.001128062	0.001128062	0.020	0.8901
ERROR	22	1.27047098	0.05774868		
C TOTAL	23	1.27159904			

ROOT MSE	0.2403096	R-SQUARE	0.0009
DEP MEAN	-0.335376	ADJ R-SQ	-0.0445
C.V.	-71.6537		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-0.43784632	0.73480354	-0.596	0.5573
LMW	1	0.01677068	0.11999284	0.140	0.8901

where all variables are as defined in Equation 3.1.11 except that the following nine time dummy variables, representing year of construction start, replace T65, a continuous time variable:

DUM_1 = 1 if 1968, otherwise 0;

DUM_2 = 1 if 1969, otherwise 0;

DUM_3 = 1 if 1970, otherwise 0;

DUM_4 = 1 if 1971, otherwise 0;

DUM_5 = 1 if 1972, otherwise 0;

DUM_6 = 1 if 1973, otherwise 0;

DUM_7 = 1 if 1974, otherwise 0;

DUM_8 = 1 if 1976, otherwise 0;

DUM_9 = 1 if 1977, otherwise 0;

Intercept = 1967

Tables 3.7.10 through 3.7.14 show the cross-sectional results. The coefficients of ln CAP reflect disturbances caused by small numbers of observations combined with great variance in the other terms and seem to offer no insights into a possible time trend. The coefficients of ln CAP ranged from .51 in 1973-1974 to -.81 in 1971-1972.

Equation 3.7.2 estimated on the total data for all years yielded the coefficients shown in Table 3.7.15. These coefficients were used to treat the LWR data in the second model specification. They adjusted the cost data of nuclear units for the estimated effects for all variables in the equation except ln CAP. The results are shown in Tables 3.7.16 through 3.7.20.

It can be seen from the tables that the treatment procedure provided some smoothing to the pattern of annual variation in the coefficients of ln CAP, but, again, no time trend in the coefficient of ln CAP is evident. This seems to confirm the earlier finding that too much variance exists in

Table 3.7.10. Cross-Section Regression for Nuclear Units: 1967-1968.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.98181588	0.49545397	6.440	0.0010
ERROR	25	1.92324709	0.07692988		
C TOTAL	29	3.90506297			

ROOT MSE	0.2773624	R-SQUARE	0.5075
DEP MEAN	6.748658	ADJ R-SQ	0.4287
C.V.	4.109889		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.39552480	1.45937766	4.382	0.0002
LMW	1	0.06757956	0.21741529	0.311	0.7585
FIRST	1	0.07863258	0.11311102	0.695	0.4934
SOUTH	1	-0.42252259	0.11787324	-3.585	0.0014
E79	1	0.36018408	0.22284686	1.616	0.1186

Table 3.7.11. Cross-Section Regression for Nuclear Units: 1969-1970.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.08499531	0.02124883	0.650	0.6375
ERROR	12	0.39212782	0.03267732		
C TOTAL	16	0.47712313			

ROOT MSE	0.1807687	R-SQUARE	0.1781
DEP MEAN	7.1429	ADJ R-SQ	-0.0958
C.V.	2.530747		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.81495302	2.18677284	3.116	0.0089
LMW	1	0.04298993	0.32146590	0.134	0.8958
FIRST	1	0.07184758	0.09763873	0.736	0.4760
SOUTH	1	-0.09508762	0.10035323	-0.948	0.3621
E79	1	0.17837397	0.15364508	1.161	0.2682

Table 3.7.12. Cross-Section Regression for Nuclear Units: 1971-1972.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.47012184	0.36753046	5.494	0.0133
ERROR	10	0.66892905	0.06689290		
C TOTAL	14	2.13905088			

ROOT MSE	0.2586366	R-SQUARE	0.6873
DEP MEAN	7.308514	ADJ R-SQ	0.5622
C.V.	3.53884		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	12.34459045	2.07589234	5.947	0.0001
LMW	1	-0.80634914	0.31242376	-2.581	0.0274
FIRST	1	0.37313691	0.16953128	2.201	0.0524
SOUTH	1	0.03200615	0.19039997	0.168	0.8699
E79	1	0.35547945	0.13768926	2.582	0.0273

Table 3.7.13. Cross-Section Regression for Nuclear Units: 1973-1974.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	0.26319720	0.08773240	0.903	0.4734
ERROR	10	0.97133502	0.09713350		
C TOTAL	13	1.23453222			

ROOT MSE	0.3116625	R-SQUARE	0.2132
DEP MEAN	7.668294	ADJ R-SQ	-0.0228
C.V.	4.0643		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	4.06088848	7.41457861	0.548	0.5959
LMW	1	0.51479901	1.05991574	0.486	0.6376
FIRST	1	0.21332094	0.17407578	1.225	0.2485
SOUTH	1	-0.25460930	0.18278359	-1.393	0.1938

Table 3.7.14. Cross-Section Regression for Nuclear Units: 1976-1977.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	0.11984379	0.03994793	1.112	0.4266
ERROR	5	0.17965347	0.03593069		
C TOTAL	8	0.29949726			

ROOT MSE	0.1895539	R-SQUARE	0.4001
DEP MEAN	7.788722	ADJ R-SQ	0.0402
C.V.	2.433697		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	4.82985501	3.04821030	1.584	0.1739
LMW	1	0.45086978	0.43266339	1.042	0.3451
FIRST	1	-0.03786667	0.14478379	-0.262	0.8041
SOUTH	1	-0.23436894	0.17336259	-1.352	0.2343

Table 3.7.15. Cross-Section/Time-Series Pooled Regression for Nuclear Units: 1967-1977.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	16.09125658	1.23778897	18.427	0.0001
ERROR	75	5.03784604	0.06717128		
C TOTAL	88	21.12910262			

ROOT MSE	0.2591742	R-SQUARE	0.7616
DEP MEAN	7.200759	ADJ R-SQ	0.7202
C.V.	3.599263		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.84932108	0.99972500	6.851	0.0001
LMW	1	-0.01960892	0.14784804	-0.133	0.8948
FIRST	1	0.17379466	0.05879155	2.956	0.0042
SOUTH	1	-0.29995721	0.06361557	-4.715	0.0001
E79	1	0.42820325	0.09238183	4.635	0.0001
D68	1	0.08979475	0.09321462	0.963	0.3385
D69	1	0.39334689	0.12388541	3.175	0.0022
D70	1	0.34525472	0.10691779	3.229	0.0018
D71	1	0.29448383	0.14757543	1.995	0.0496
D72	1	0.48143891	0.11532918	4.174	0.0001
D73	1	0.43724965	0.14063701	3.109	0.0027
D74	1	0.66943381	0.13049339	5.130	0.0001
D76	1	0.82731587	0.13813745	5.989	0.0001
D77	1	0.63902462	0.20885519	3.060	0.0031

Table 3.7.16. Cross-Section Regression of Treated Nuclear Unit Data: 1967-1968.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.009518937	0.009518937	0.144	0.7072
ERROR	28	1.85090391	0.06610371		
C TOTAL	29	1.86042285			

ROOT MSE	0.2571064	R-SQUARE	0.0051
DEP MEAN	-0.164581	ADJ R-SQ	-0.0304
C.V.	-156.219		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-0.63061271	1.22899917	-0.513	0.6119
LMW	1	0.06943610	0.18298017	0.379	0.7072

Table 3.7.17. Cross-Section Regression of Treated Nuclear Unit Data: 1969-1970.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01313307	0.01313307	0.350	0.5630
ERROR	15	0.56292933	0.03752862		
C TOTAL	16	0.57606240			

ROOT MSE	0.1937231	R-SQUARE	0.0228
DEP MEAN	-0.133186	ADJ R-SQ	-0.0423
C.V.	-145.453		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	0.89916054	1.74574569	0.515	0.6140
LMW	1	-0.15199207	0.25693254	-0.592	0.5630

Table 3.7.18. Cross-Section Regression of Treated Nuclear Unit Data: 1971-1972.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.25948851	0.25948851	3.973	0.0676
ERROR	13	0.84899216	0.06530709		
C TOTAL	14	1.10848067			

ROOT MSE	0.2555525	R-SQUARE	0.2341
DEP MEAN	-0.133618	ADJ R-SQ	0.1752
C.V.	-191.256		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	3.64664227	1.89760371	1.922	0.0768
LMW	1	-0.55476632	0.27831152	-1.993	0.0676

Table 3.7.19. Cross-Section Regression of Treated Nuclear Unit Data: 1973-1974.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.001680524	0.001680524	0.024	0.8792
ERROR	12	0.83702572	0.06975214		
C TOTAL	13	0.83870625			

ROOT MSE	0.2641063	R-SQUARE	0.0020
DEP MEAN	-0.137501	ADJ R-SQ	-0.0812
C.V.	-192.076		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	0.80146198	6.04971020	0.132	0.8968
LMW	1	-0.13390462	0.86268450	-0.155	0.8792

Table 3.7.20. Cross-Section Regression of Treated Nuclear Unit Data: 1976-1977.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01375411	0.01375411	0.352	0.5718
ERROR	7	0.27371573	0.03910225		
C TOTAL	8	0.28746985			

ROOT MSE	0.1977429	R-SQUARE	0.0478
DEP MEAN	-0.137528	ADJ R-SQ	-0.0882
C.V.	-143.784		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-2.00946541	3.15697105	-0.637	0.5447
LMW	1	0.26690354	0.45002734	0.593	0.5718

the ln cost/kW - ln CAP relationship relative to the number of annual observations to identify a time trend even if one exists.

Analysis comparable to that shown in Table 3.7.10, but with IDC excluded, was also performed, and the results are shown in Appendix B. This analysis resulted in an overall coefficient of -.30 for ln CAP when using ln (C/KW) without IDC, but it was not significantly different from zero (t = -.696) at a conventional level of probability. Cross-sectional analysis of the treated and untreated data without IDC (only a total of 31 observations was available) did not reveal any statistically significant results or trends and it was not appended.

3.8 ANALYSIS OF DATA PARTITIONED BY CAPACITY

The next series of analyses was made to evaluate the possibility that the coefficient of ln CAP has a trend over the range of unit capacities, indicating more or less economy of scale as unit capacity increases. Using a methodology similar to that used in the previous section, which examined the coefficient of ln CAP cross-sectionally with respect to time of construction start, in this section the data are partitioned by unit capacity range. Analysis is then performed on the untreated and treated data. The data analyzed here include IDC, but regressions were also performed on the data excluding IDC. They are shown in Appendix B.

Before proceeding with the analysis it should be noted that, by partitioning the data by range of MW capacity and then fitting least-square slopes of ln (C/KW) with respect to ln CAP, a statistical bias may be introduced which may increase the slope, either positively or negatively. Referring to Figures 2.1.1 and 2.1.2, showing plots of ln (C/KW) versus ln CAP for coal and nuclear units, the reader can select random segments along the x-axis and verify that the data trends may become extreme as the x segment is shortened. Therefore, the coefficients of ln CAP obtained in the succeeding capacity-partitioning analysis should be viewed with caution.

Equation 3.7.1 was estimated on three size groups of coal plants: 400 MW and less; 401-600 MW; and 601-850 MW. The results are shown in Tables 3.8.1 through 3.8.3 for the untreated data, indicating a scaling exponent range from 0.00 to 1.05.

From these tables it can be seen that the regressions on the untreated data partitioned by size indicate that economy of scale might increase with unit capacity although the regressions on size-partitioned data do not produce realistic magnitudes of the coefficient of ln CAP. For example, Table 3.8.3 would indicate that increasing the capacity of a unit in the 601-850 MW range would not increase its total cost.

Tables 3.8.4 through 3.8.6 show the simple regression results from size-partitioned groups using treated data and solving for the intercept and coefficient of ln CAP. These results also indicate that economy of scale may increase with unit capacity, but, again, the magnitude of the coefficients of ln CAP seem unrealistic.

Table 3.8.1. Regression of Coal Units Partitioned by Capacity: 0-400 MW.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	10	2.75440309	0.27544031	4.114	0.0060
ERROR	16	1.07134675	0.06695917		
C TOTAL	26	3.82574984			

ROOT MSE	0.2587647	R-SQUARE	0.7200
DEP MEAN	6.796173	ADJ R-SQ	0.5449
C.V.	3.807506		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.38322909	1.11042540	5.748	0.0001
LMW	1	0.05234607	0.19167287	0.273	0.7883
FIRST	1	0.38113521	0.11100529	3.433	0.0034
SOUTH	1	-0.06811073	0.12124283	-0.562	0.5821
DFGD	1	0.26472756	0.10794563	2.452	0.0260
D74	1	-0.51138163	0.31072445	-1.646	0.1193
D75	1	-0.14986342	0.17446865	-0.859	0.4030
D76	1	-0.31639469	0.23313512	-1.357	0.1936
D77	1	-0.59764963	0.24192315	-2.470	0.0251
D78	1	-0.14439550	0.17140327	-0.842	0.4120
D79	1	-0.27864638	0.20754991	-1.343	0.1982

Table 3.8.2. Regression of Coal Units Partitioned by Capacity: 401-600 MW.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	11	3.45575307	0.31415937	5.889	0.0001
ERROR	26	1.38692525	0.05334328		
C TOTAL	37	4.84267833			

ROOT MSE	0.2309616	R-SQUARE	0.7136
DEP MEAN	6.719696	ADJ R-SQ	0.5924
C.V.	3.437085		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	9.37526075	2.50617319	3.741	0.0009
LMW	1	-0.36532380	0.40931055	-0.893	0.3803
FIRST	1	0.40939055	0.08119106	5.042	0.0001
SOUTH	1	-0.14706886	0.10217620	-1.439	0.1620
DFGD	1	0.21198735	0.10844455	1.955	0.0614
D74	1	-0.66578549	0.28263859	-2.356	0.0263
D75	1	-0.53187766	0.29644538	-1.794	0.0844
D76	1	-0.67096462	0.29317413	-2.289	0.0305
D77	1	-0.68097737	0.27773953	-2.452	0.0212
D78	1	-0.69147385	0.27924443	-2.476	0.0201
D79	1	-0.34679079	0.27561587	-1.258	0.2195
D80	1	-0.53200043	0.28059617	-1.896	0.0691

Table 3.8.3. Regression of Coal Units Partitioned by Capacity: 601-850 MW.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	12	3.44453881	0.28704490	5.172	0.0001
ERROR	30	1.66490440	0.05549681		
C TOTAL	42	5.10944320			

ROOT MSE	0.2355776	R-SQUARE	0.6742
DEP MEAN	6.667437	ADJ R-SQ	0.5438
C.V.	3.533256		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	12.94942304	3.14002187	4.124	0.0003
LMW	1	-1.00452845	0.48135259	-2.087	0.0455
FIRST	1	0.30565274	0.08511799	3.591	0.0012
SOUTH	1	-0.08101687	0.09315222	-0.870	0.3914
DFGD	1	-0.05692929	0.10498008	-0.542	0.5916
D74	1	0.11808363	0.17137047	0.689	0.4961
D75	1	-0.26109544	0.30452806	-0.857	0.3980
D76	1	0.14728298	0.21732746	0.678	0.5032
D77	1	-0.07189983	0.19996501	-0.360	0.7217
D78	1	0.23173722	0.16287689	1.423	0.1651
D79	1	0.31405829	0.18537885	1.694	0.1006
D80	1	0.71632499	0.30808295	2.325	0.0270
D81	1	0.51476676	0.20082441	2.563	0.0156

Table 3.8.4. Regression of Treated Coal Unit Data Partitioned by Capacity: 0-400 MW.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01557392	0.01557392	0.275	0.6046
ERROR	25	1.41532504	0.05661300		
C TOTAL	26	1.43089896			

ROOT MSE	0.2379349	R-SQUARE	0.0109
DEP MEAN	-0.329652	ADJ R-SQ	-0.0287
C.V.	-72.1776		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-0.76758220	0.83621178	-0.918	0.3674
LMW	1	0.07839498	0.14946770	0.524	0.6046

Table 3.8.5. Regression of Treated Coal Unit Data Partitioned by Capacity: 401-600 MW.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.11479551	0.11479551	2.208	0.1460
ERROR	36	1.87171312	0.05199203		
C TOTAL	37	1.98650863			

ROOT MSE	0.2280176	R-SQUARE	0.0578
DEP MEAN	-0.302299	ADJ R-SQ	0.0316
C.V.	-75.4278		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	2.86085523	2.12907953	1.344	0.1875
LMW	1	-0.51089466	0.34382488	-1.486	0.1460

Table 3.8.6. Regression of Treated Coal Unit Data Partitioned by Capacity: 601-850 MW.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.19522259	0.19522259	3.457	0.0702
ERROR	41	2.31543078	0.05647392		
C TOTAL	42	2.51065337			

ROOT MSE	0.2376424	R-SQUARE	0.0778
DEP MEAN	-0.3774	ADJ R-SQ	0.0553
C.V.	-62.9683		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	4.61360378	2.68464219	1.719	0.0932
LMW	1	-0.76376833	0.41079069	-1.859	0.0702

The regressions (included in Appendix B) on size-partitioned groups which exclude IDC parallel the results of the data which include IDC, but the magnitudes of the scaling exponents are somewhat less extreme and are not significant at the .05 level of probability.

In view of the caveats expressed earlier in this section and a lack of statistical significance of most of the coefficients of ln CAP in the various size-partitioned regressions and their unrealistic magnitudes, the strongest statement that can reasonably be made is that economy of scale may increase with unit capacity. However, over the entire range of unit capacity in the CRA-EEI data base, there is no evidence of significant economy of scale in the construction of coal-fired units.

Equation 3.7.2 was estimated on two size-groups of nuclear plants: less than 1000 MW and 1000 MW and larger. The results are shown in Tables 3.8.7 and 3.8.8 for the untreated data.

The tables show that the economy of scale decreased drastically when units under 1000 MW are compared to units of 1000 MW and over, i.e., the coefficient of ln MW changed from -.37 to 2.49, corresponding to a scaling exponent change from 0.63 to 3.49.

Tables 3.8.9 and 3.8.10 show the results of the simple regressions on the same size categories of nuclear units using the treated data. This procedure greatly reduced the absolute values of the coefficients of ln CAP and showed the same trend as in the untreated data where scale economy decreased with unit capacity.

There was an insufficient number of nuclear units with IDC reported separately to estimate coefficients of ln CAP for different capacity ranges on the basis of costs exclusive of IDC.

Table 3.8.7. Regression of Nuclear Units Partitioned by Capacity: 0-1000 MW.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	12	7.72684786	0.64390399	12.732	0.0001
ERROR	32	1.61835008	0.05057344		
C TOTAL	44	9.34519794			

ROOT MSE	0.2248854	R-SQUARE	0.8268
DEP MEAN	7.011494	ADJ R-SQ	0.7619
C.V.	3.207382		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	8.86427318	1.36493690	6.494	0.0001
LMW	1	-0.36630270	0.20794597	-1.762	0.0877
FIRST	1	0.13978109	0.08111763	1.723	0.0945
SOUTH	1	-0.20868443	0.08717096	-2.394	0.0227
E79	1	0.20759403	0.14989393	1.385	0.1757
D68	1	0.34017214	0.11088739	3.068	0.0044
D69	1	0.74088773	0.14530923	5.099	0.0001
D70	1	0.65936372	0.12399736	5.318	0.0001
D71	1	0.80260581	0.17037476	4.711	0.0001
D72	1	0.94228418	0.14777331	6.377	0.0001
D73	1	1.05760589	0.29699739	3.561	0.0012
D76	1	1.26863090	0.28674999	4.424	0.0001
D77	1	1.17715129	0.29827967	3.946	0.0004

Table 3.8.8. Regression of Nuclear Units Partitioned by Capacity: 1001 MW and over.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	13	6.77034575	0.52079583	8.913	0.0001
ERROR	30	1.75301775	0.05843392		
C TOTAL	43	8.52336349			

ROOT MSE	0.2417311	R-SQUARE	0.7943
DEP MEAN	7.394325	ADJ R-SQ	0.7052
C.V.	3.269144		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-10.42647843	7.88299474	-1.323	0.1959
LMW	1	2.49269356	1.13421773	2.198	0.0358
FIRST	1	0.19754602	0.07736320	2.553	0.0160
SOUTH	1	-0.43412118	0.12215442	-3.554	0.0013
E79	1	0.28245295	0.15653667	1.804	0.0812
D68	1	-0.09273547	0.13415640	-0.691	0.4947
D69	1	0.06302695	0.21143079	0.298	0.7677
D70	1	0.09184546	0.18982193	0.484	0.6320
D71	1	-0.49529810	0.28787988	-1.721	0.0956
D72	1	0.11626359	0.19132658	0.608	0.5480
D73	1	0.24924988	0.15527148	1.605	0.1189
D74	1	0.45574691	0.15139695	3.010	0.0053
D76	1	0.53191078	0.17273969	3.079	0.0044
D77	1	0.31280326	0.27033880	1.157	0.2564

Table 3.8.9. Regression of Treated Nuclear Unit Data Partitioned by Capacity: 0-1000 MW.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01645519	0.01645519	0.297	0.5885
ERROR	43	2.38181707	0.05539109		
C TOTAL	44	2.39827226			

ROOT MSE	0.2353531	R-SQUARE	0.0069
DEP MEAN	-0.135623	ADJ R-SQ	-0.0162
C.V.	-173.535		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	0.51287054	1.19031669	0.431	0.6687
LMW	1	-0.09752489	0.17893032	-0.545	0.5885

Table 3.8.10. Regression of Treated Nuclear Unit Data Partitioned by Capacity: 1001 MW and over.

DEP VARIABLE: LC84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01382433	0.01382433	0.221	0.6407
ERROR	42	2.62745815	0.06255853		
C TOTAL	43	2.64128248			

ROOT MSE	0.250117	R-SQUARE	0.0052
DEP MEAN	-0.132435	ADJ R-SQ	-0.0185
C.V.	-188.86		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-2.37514308	4.77097906	-0.498	0.6212
LMW	1	0.31916747	0.67895321	0.470	0.6407

3.9 ANALYSIS OF DATA FOR COAL-FIRED PLANTS PARTITIONED BY FGD AND NON-FGD

In the case of coal plants it was also possible to partition the data by units with and without FGD and make separate estimates of the coefficient of ln CAP in each group. Since the New Source Performance Standards promulgated in 1978 increased the cost of "covered" units only, merging FGD and non-FGD data could bias the estimate of both the cost-time and cost-capacity trends.

Equation 3.1.12 was estimated separately for units with and without FGD; the regression results are shown in Tables 3.9.1 and 3.9.2, respectively. Both data sets included IDC.

It can be seen in the tables that the coefficient of ln CAP for the units with FGD more than doubled compared to the original regression on the data set including both FGD and non-FGD units (Table 3.1.2) and approached significance at the 0.1 level of probability. The coefficient for non-FGD units changed very little from the original coefficient.

Similar regressions were also run on the FGD units and non-FGD units, separately, for costs without IDC. The results are shown in Tables 3.9.3 and 3.9.4, respectively. The coefficient of ln CAP for the non-FGD units is about half the value of the coefficient in the analysis of costs with IDC for non-FGD units, while the coefficient of ln CAP for the FGD units is about twice the value of that for the analysis of costs with IDC for FGD units. However, neither coefficient was significant even at the 0.1 level of significance.

Although not shown in this report, several different variants of regressions were also estimated for the FGD and non-FGD units, separately, using both ln CAP and $(\ln \text{CAP})^2$ and T65 and $(\text{T65})^2$ in addition to a time dummy variable to capture the effect of the New Source Performance Standards. The results may be summarized as: (a) the coefficient of ln CAP was always positive, while the coefficient of $(\ln \text{CAP})^2$ was always negative, indicating that economy of scale increased with unit size; (b) real cost per kW of FGD units increased at an average of 6.1 percent per year, but when a time dummy variable (equalling one for units beginning construction in 1979 or after and equalling zero otherwise) was added to the equation, an annual cost growth rate of 2.1 percent was estimated with a 27 percent jump in cost for units with FGD beginning in 1979 or after; and (c)

Table 3.9.1. Regression Results for Coal Units with FGD: IDC included.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	2.78455922	0.69613980	13.839	0.0001
ERROR	43	2.16309032	0.05030443		
C TOTAL	47	4.94764954			

ROOT MSE	0.2242865	R-SQUARE	0.5628
DEP MEAN	6.901868	ADJ R-SQ	0.5221
C.V.	3.249649		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.70071707	0.49805744	13.454	0.0001
LMW	1	-0.13198210	0.08123817	-1.625	0.1115
FIRST	1	0.34988281	0.06627456	5.279	0.0001
SOUTH	1	-0.13728485	0.07239870	-1.896	0.0647
T65	1	0.06474293	0.01535940	4.215	0.0001

Table 3.9.2. Regression Results for Coal Units without FGD: IDC included.

DEP VARIABLE: LC84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	2.05029942	0.51257486	6.819	0.0002
ERROR	55	4.13426116	0.07516838		
C TOTAL	59	6.18456059			

ROOT MSE	0.2741685	R-SQUARE	0.3315
DEP MEAN	6.570921	ADJ R-SQ	0.2829
C.V.	4.172452		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.66442673	0.67393379	9.889	0.0001
LMW	1	-0.06148400	0.09289962	-0.662	0.5108
FIRST	1	0.32534095	0.07605911	4.277	0.0001
SOUTH	1	-0.10338685	0.07355543	-1.406	0.1655
T65	1	0.01748304	0.02091841	0.836	0.4069

Table 3.9.3. Regression Results for Coal Units With FGD: IDC Excluded.

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.56810841	0.39202710	8.469	0.0001
ERROR	35	1.62012914	0.04628940		
C TOTAL	39	3.18823755			

ROOT MSE	0.2151497	R-SQUARE	0.4918
DEP MEAN	6.777563	ADJ R-SQ	0.4338
C.V.	3.174441		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.25604477	0.49758651	12.573	0.0001
LMW	1	-0.06142333	0.08971955	-0.685	0.4981
FIRST	1	0.25304974	0.07153817	3.537	0.0012
SOUTH	1	-0.15243666	0.07227970	-2.109	0.0422
T65	1	0.05925004	0.01827759	3.242	0.0026

Table 3.9.4. Regression for Coal Units Without FGD: IDC Excluded.

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	2.46033826	0.61508457	10.215	0.0001
ERROR	49	2.95037536	0.06021174		
C TOTAL	53	5.41071362			

ROOT MSE	0.2453808	R-SQUARE	0.4547
DEP MEAN	6.418655	ADJ R-SQ	0.4102
C.V.	3.822932		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	7.00541584	0.64272954	10.899	0.0001
LMW	1	-0.14902364	0.09120494	-1.634	0.1087
FIRST	1	0.33140463	0.07072984	4.685	0.0001
SOUTH	1	-0.12301693	0.06963075	-1.767	0.0835
T65	1	0.02280099	0.01945733	1.172	0.2469

real cost per kW of non-FGD units increased at an average 1.7 percent annually.

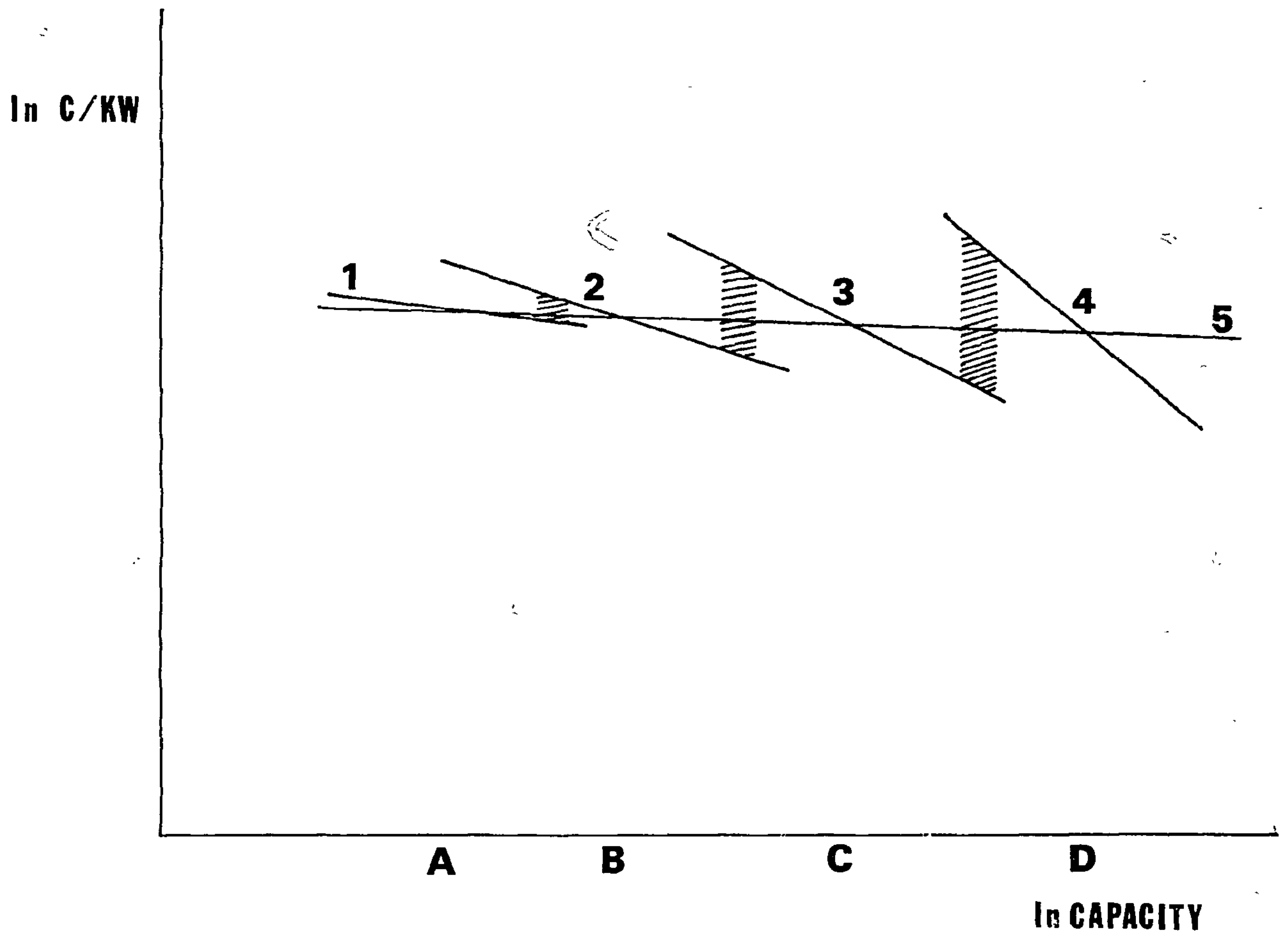
The sparsity of and variance in the data do not allow a definitive answer to the question of whether scaling might exist in narrow capacity ranges, yet not be statistically observable over the entire capacity range.

Consider the curves 1,2,3 and 4 (in solid line) in Figure 3.9.1. These curves represent hypothetical scaling functions for power plants in the A range of capacity, B range of capacity, C range of capacity and D range of capacity, respectively. The hatched areas connecting the curves reflect step functions in cost as boundaries between capacity-specific design technologies are crossed.

Taken individually, curves 1,2,3 and 4, compared with one another, show that economy of scale increases discretely but not continuously with capacity, but a least-squares regression line fitted to the entire data set would be approximated by Curve 5. This least-square fit would show little continuous economy of scale when, in fact, economy of scale exists but only in discrete capacity ranges.

The question of whether economy of scale is a continuous or discrete phenomenon over the range of capacities included in the CRA-EEI coal-fired and LWR data bases, is as much an engineering question as it is a statistical one and cannot be answered within the purview of this study.

Figure 3.9.1. Plot of ln C/KW vs. ln CAPACITY showing possible economy of scale in discrete capacity ranges.



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APPENDIX A

SUPPLEMENTARY DATA BASE INFORMATION

APPENDIX A

Method for Converting Capital Costs from Mixed Current Dollars to 1984 Dollars

This appendix explains a step-by-step method for computing the capital costs in constant dollars (1984 dollars) from mixed current dollars for LWR and coal-fired powerplants.

Step 1: Cash Flow Percents of Costs in Current Dollars

The annual cash flow percents of capital costs in current dollars are estimated for a particular powerplant by utilizing the following cash flow equations (for a graphic illustration of the equations see Figure A1):

$$Y = \left\{1 - [\cos(\pi x/2)]^{2.21}\right\}^{2.42} \quad \text{for LWR} \qquad (A1)$$

$$Y = \left\{1 - [\cos(\pi x/2)]^{2.31}\right\}^{2.61} \quad \text{for coal-fired} \qquad (A2)$$

where Y = fraction of cumulative costs (cash flow):

x = fraction of total period, which is measured from the date of steam supply system order to the end of construction, $0 \leq x \leq 1$.

Annual cash flow percent F_t for each year t is calculated from equation (A1) or (A2) as follows:

$$F_t = Y_t - Y_{t-1} \qquad (A3)$$

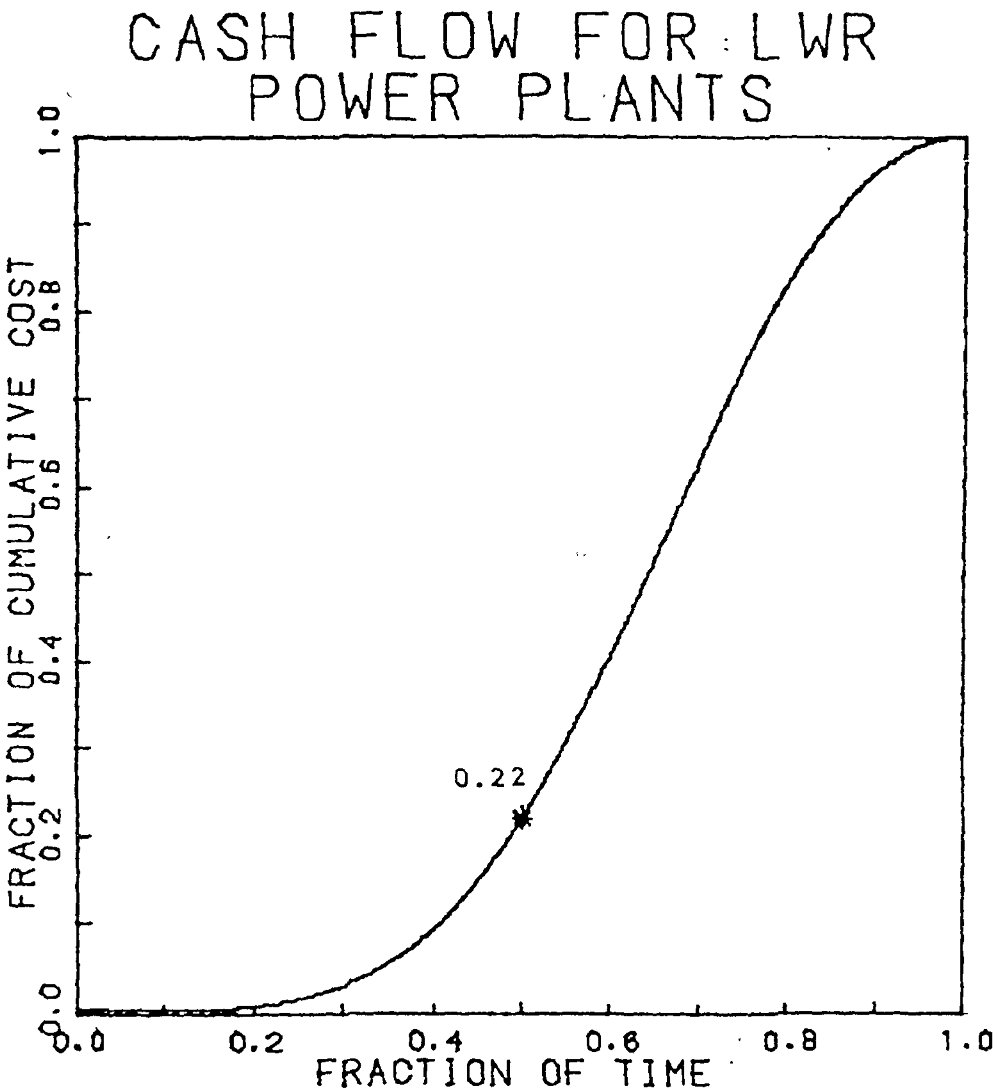
where t is the reference year.

Step 2: Cost Distribution in Current Dollars

Total capital costs in mixed current dollars reported from utilities are distributed over the years of the reference period by:

$$COST_t = \overline{TC} \cdot F_t \qquad (A4)$$

Figure A1.


CASH FLOW FOR LWR
POWER PLANTS
FRACTION OF CUMULATIVE COST
0.0
0.2
0.4
0.6
0.8
1.0
0.22
0.0
0.2
0.4
0.6
0.8
1.0
FRACTION OF TIME

where $COST_t$ = annual cost in current dollars for year t;

TC = total reported costs in mixed current dollars.

Step 3: Capital Costs in 1984 Dollars

The Handy-Whitman index for Total Plant-All Steam Generation (1972=1000) was utilized in coverting costs from mixed current dollars to 1984 dollars as follows:

$$CCOST_t = COST_t \cdot (HWI_{t_0} / HWT_t) \qquad \text{(A5)}$$

where $CCOST_t$ = annual costs in 1984 dollars;

HWI_{t_0} = Handy-Whitman Index for Total Plant-All Steam Generation in the year t_0 (1984);

HWI_t = Handy-Whitman Index for Total Plant-All Steam Generation in the year t.

The Handy-Whitman Index for Total Plant-All Steam Generation is:

Year	H-W Index	Year	H-W Index
1960	660	1976	1580
1961	650	1977	1690
1962	660	1978	1790
1963	660	1979	1970
1964	670	1980	2146
1965	690	1981	2349
1966	710	1982	2467
1967	742	1983	2552
1968	762	1984	2659*
1969	813	1985	2771
1970	879	1986	2887
1971	946	1987	3009
1972	1000	1988	3135
1973	1070	1989	3267
1974	1270	1990	3204
1975	1490	1991	3547

*estimated to increase 4.2 percent annually after 1984.

Hence, total capital costs (TCC) in 1984 dollars for a specific powerplant unit under consideration are estimated as a sum of annual costs in 1984 dollars over the period:

$$TCC = \sum_{t=t_1}^{t=m} CCOST_t \qquad (A6)$$

where t_1 = the year of construction start;

t_m = the year of construction end.

APPENDIX A

Survey of Capital and Labor Requirements for Recently Constructed Steam-Electric Generating Units

____
Name of Utility

______________________	______________	______________ MWe
Name of Powerplant	Unit Number	Net Capacity

1. What is the estimated cost (including escalation) of the unit by category?

(See attachment for description of categories)

Direct Costs	$ Costs (000)
a. Land and Land Rights	$ __________
b. Structures and Improvements	__________
c. Boiler Plant	__________
d. Turbine Plant	__________
e. Electric Plant	__________
f. Miscellaneous	__________
Indirect Costs	
g. Construction Services	__________
h. Home Office Engineering Service	__________
i. Field Office Engineering Service	__________
j. Owner's Costs	__________
Interest	
k. Interest during Construction	__________
TOTAL PLANT CAPITAL INVESTMENT	$ __________

(continued)

2. Construction Start Date: __________ Completion Date: ____________.
month/year (Actual or Estimated) month/year

3. What percent of the field labor was covered by a union contract? _______%.

4. Does this unit have Flue Gas Desulfurization (FGD) equipment? Yes__ No__

   a. If yes, what percent of total cost is attributable to FGD? __________%.

   b. If yes, does the cost estimate include costs associated with waste disposal?
   ______________________________.

5. What are the estimated on-site manual workhour requirements (INCLUDE working foremen, craftsmen, apprentices, helpers and laborers) for direct and indirect (INCLUDE site preparation, material handling, temporary structures, etc.) construction of this unit? INCLUDE all subcontractors; Exclude on-site technical and other non-manual workers.

TOTAL ON-SITE MANUAL WORKHOURS __________

6. Name of Person Completing Questionnaire:

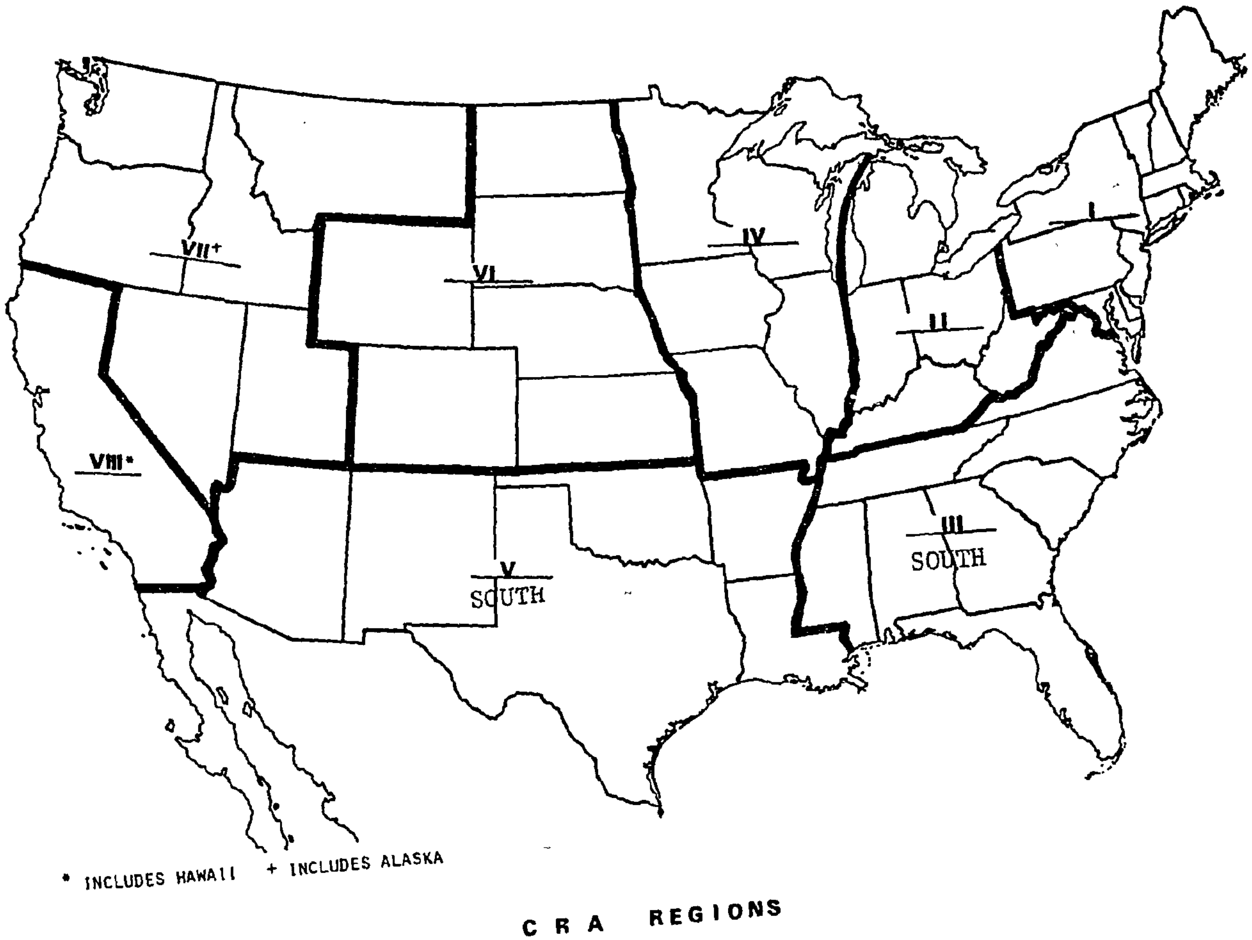
____________________ ____________________
Name Title

____________________ ____________________
Telephone Number Date

Please Return Questionnaires to:

Construction Resources Analysis
Room 9 GBA
University of Tennessee
Knoxville, Tennessee 37996-4150

Figure A2. CRA Regions.



APPENDIX B

ANALYSES OF COSTS EXCLUDING INTEREST DURING CONSTRUCTION

Figure B.1.

LN ADJUSTED COST ($/KW IN 1984 $), WITHOUT IDC,
VS. LN CAPACITY (MW) FOR COAL-FIRED UNITS

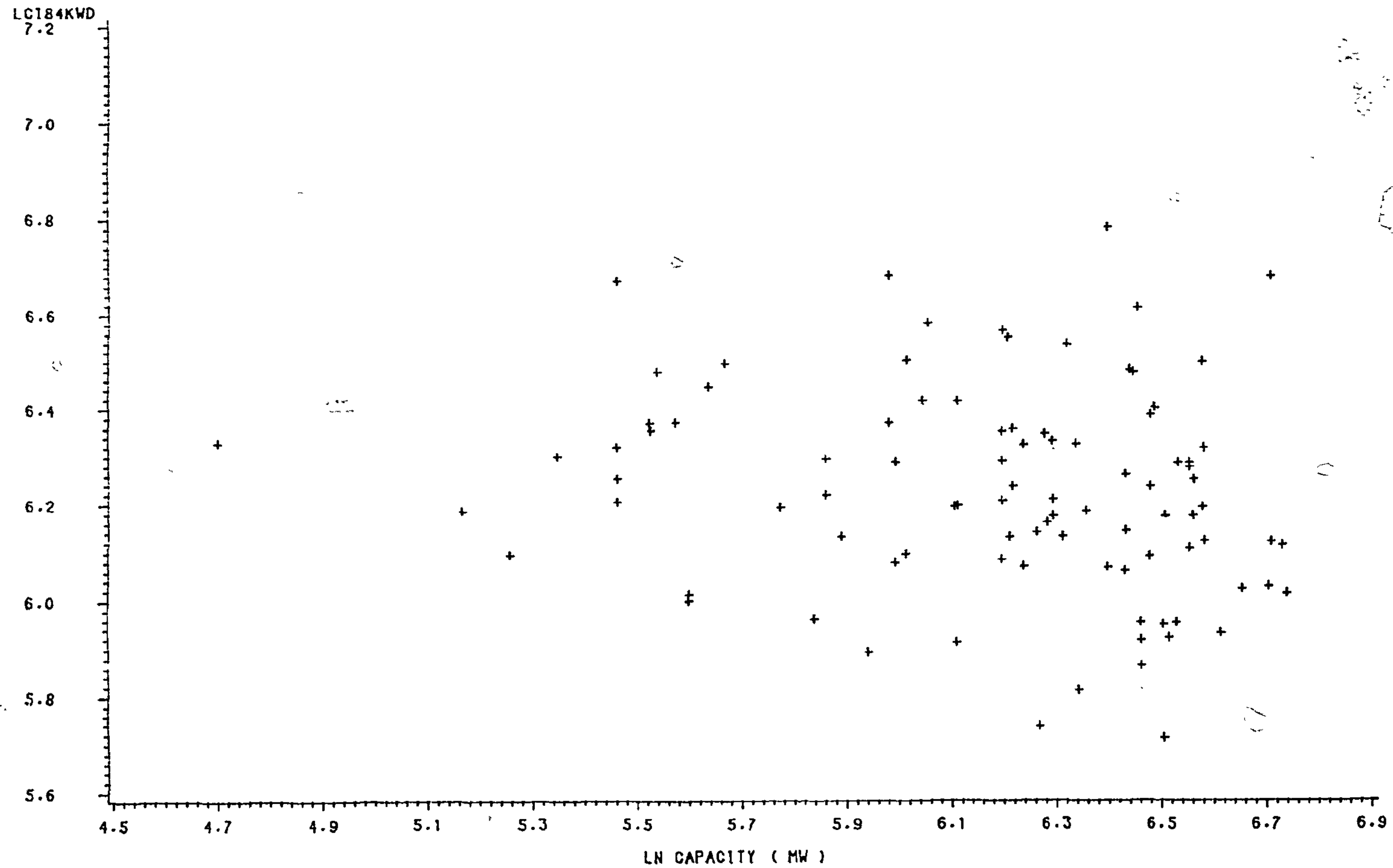


Figure B.2.

LN ADJUSTED COST ($/KW IN 1984 $), WITHOUT IDC, VS. LN CAPACITY (MW) FOR NUCLEAR UNITS

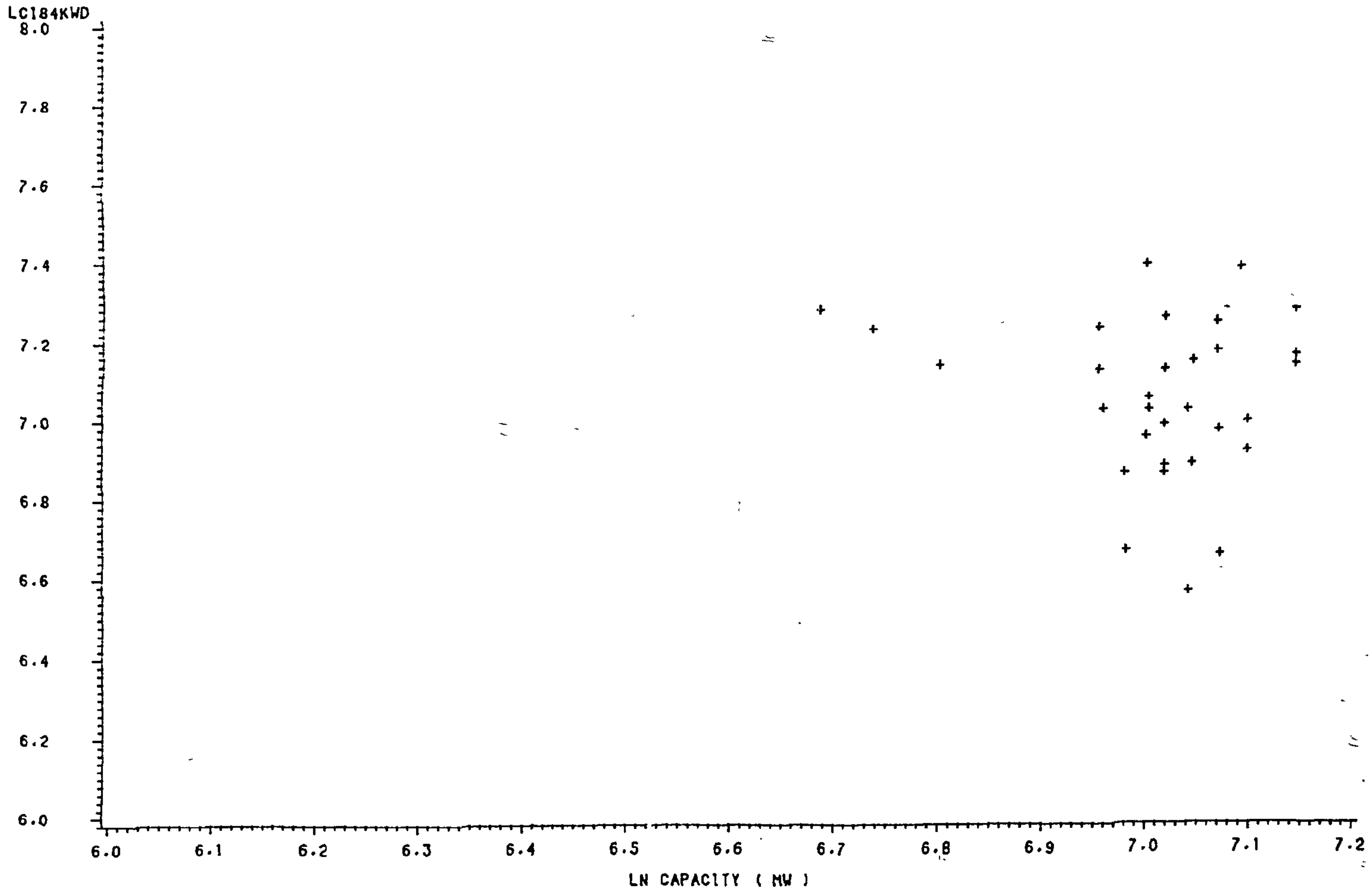


Figure B.3.

LN ADJUSTED COST ($/KW IN 1984 $), WITHOUT IDC,
VS. YEAR OF CONSTRUCTION START FOR COAL-FIRED UNITS

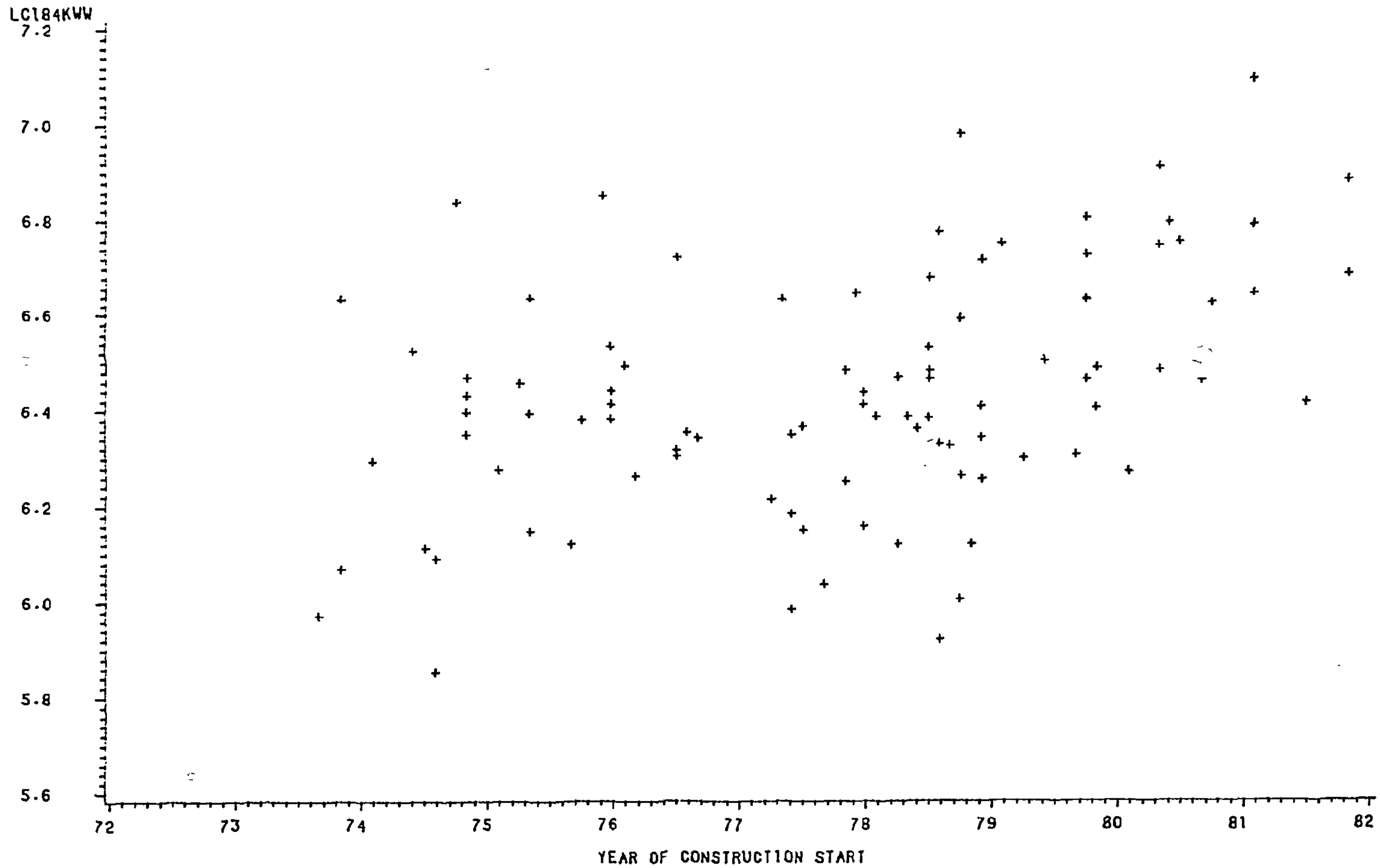


Figure B.4.

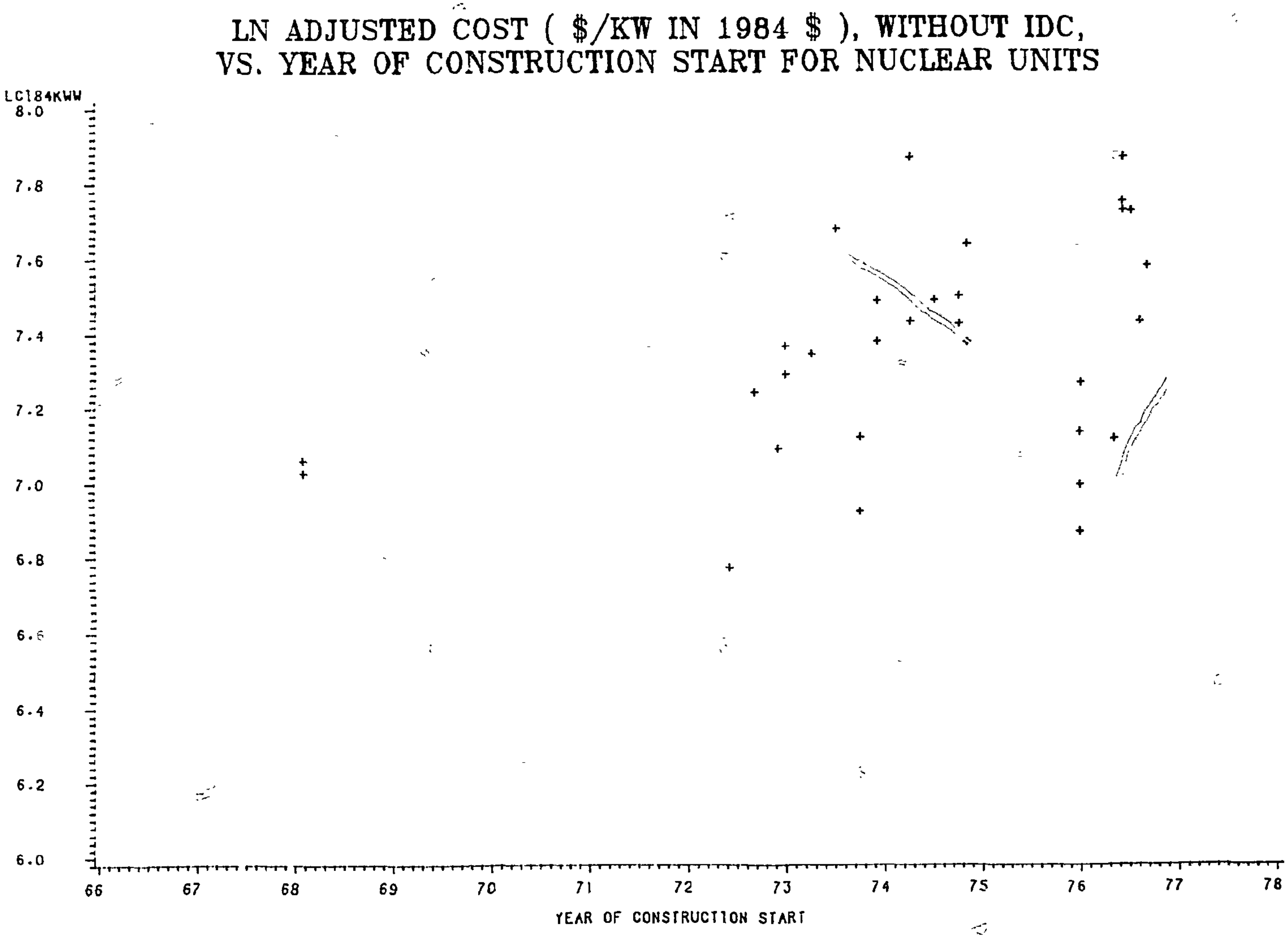

LN ADJUSTED COST ($/KW IN 1984 $), WITHOUT IDC,
VS. YEAR OF CONSTRUCTION START FOR NUCLEAR UNITS
LC184KWW
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
66
67
68
69
70
71
72
73
74
75
76
77
78
YEAR OF CONSTRUCTION START

Table B 3.7.1. Cross-Section Regression for Coal Units: 1973-1974 (IDC Excluded).

DEP VARIABLE: LC184KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.01467445	0.25366861	3.134	0.0793
ERROR	8	0.64755828	0.08094478		
C TOTAL	12	1.66223272			

ROOT MSE	0.284508	R-SQUARE	0.6104
DEP MEAN	6.317948	ADJ R-SQ	0.4156
C.V.	4.503171		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.42063312	2.19671034	2.923	0.0192
LMW	1	-0.04537977	0.33725923	-0.135	0.8963
FIRST	1	0.58005947	0.21530425	2.694	0.0273
SOUTH	1	-0.005834167	0.20489411	-0.028	0.9780
DFGD	1	0.24122660	0.33444973	0.721	0.4913

Table B 3.7.2. Cross-Section Regression for Coal Units: 1975-1976 (IDC Excluded).

DEP VARIABLE: LC184KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.63041403	0.15760351	4.208	0.0192
ERROR	14	0.52433307	0.03745236		
C TOTAL	18	1.15474710			

ROOT MSE	0.1935261	R-SQUARE	0.5459
DEP MEAN	6.533096	ADJ R-SQ	0.4162
C.V.	2.962242		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.34790019	0.79588854	7.976	0.0001
LMW	1	0.003966463	0.12985006	0.031	0.9761
FIRST	1	0.25457459	0.09508948	2.677	0.0180
SOUTH	1	-0.07891997	0.09105534	-0.867	0.4007
DFGD	1	0.25979995	0.10081511	2.577	0.0219

Table B 3.7.3. Cross-Section Regression for Coal Units: 1977-1978 (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	1.83116532	0.47029133	8.607	0.0001
ERROR	32	1.74848528	0.05464016		
C TOTAL	36	3.62965060			

ROOT MSE	0.2337524	R-SQUARE	0.5183
DEP MEAN	6.472638	ADJ R-SQ	0.4581
C.V.	3.611392		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	7.23308086	0.58752759	12.311	0.0001
LMW	1	-0.12317459	0.09446185	-1.304	0.2015
FIRST	1	0.28318195	0.07835342	3.614	0.0010
SOUTH	1	-0.26581809	0.08501020	-3.127	0.0038
DFGD	1	0.01313384	0.09486229	0.138	0.8908

Table B 3.7.4. Cross-Section Regression for Coal Units: 1979-1980 (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	4	0.68279015	0.17069754	4.602	0.0140
ERROR	14	0.51925158	0.03708940		
C TOTAL	18	1.20204173			

ROOT MSE	0.1925861	R-SQUARE	0.5680
DEP MEAN	6.863301	ADJ R-SQ	0.4446
C.V.	2.806027		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	8.26960569	0.86530940	9.557	0.0001
LMW	1	-0.25294611	0.13209268	-1.915	0.0762
FIRST	1	0.11007565	0.11982191	0.919	0.3738
SOUTH	1	-0.20412995	0.09548830	-2.138	0.0507
DFGD	1	0.20590191	0.10166765	2.025	0.0623

Table B 3.7.5. Cross-Section/Time-Series Pooled Regression for Coal Units: 1973-1981 (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	12	7.33307808	0.61108984	11.713	0.0001
ERROR	81	4.22587437	0.05217129		
C TOTAL	93	11.55895244			

ROOT MSE	0.2284104	R-SQUARE	0.6344
DEP MEAN	6.571382	ADJ R-SQ	0.5802
C.V.	3.475835		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.84512898	0.45139164	15.165	0.0001
LMW	1	-0.09996364	0.06585187	-1.518	0.1329
FIRST	1	0.28970939	0.05061757	5.723	0.0001
SOUTH	1	-0.14249958	0.05111862	-2.788	0.0066
DFGD	1	0.15099008	0.05873174	2.571	0.0120
D74	1	0.11000985	0.15466306	0.711	0.4789
D75	1	0.19344838	0.15438873	1.253	0.2138
D76	1	0.17288500	0.16504745	1.047	0.2980
D77	1	0.08193172	0.15164028	0.540	0.5905
D78	1	0.17793037	0.14582283	1.220	0.2259
D79	1	0.31889526	0.15784929	2.020	0.0467
D80	1	0.40298285	0.17142306	2.351	0.0212
D81	1	0.52379225	0.17278701	3.031	0.0033

Table B 3.7.6. Cross-Section Regression of Treated Coal Unit Data: 1973-1974 (IDC Excluded).

DEP VARIABLE: LCI84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.007074915	0.007074915	0.089	0.7707
ERROR	11	0.87211566	0.07928324		
C TOTAL	12	0.87919057			

ROOT MSE	0.2815728	R-SQUARE	0.0080
DEP MEAN	-0.636774	ADJ R-SQ	-0.0821
C.V.	-44.2187		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	-1.04376006	1.36465339	-0.765	0.4605
LMW	1	0.06389061	0.21387849	0.299	0.7707

Table B 3.7.7. Cross-Section Regression of Treated Coal Unit Data: 1975-1976 (IDC Excluded).

DEP VARIABLE: LCI84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.01561767	0.01561767	0.454	0.5093
ERROR	17	0.58418016	0.03436354		
C TOTAL	18	0.59979783			

ROOT MSE	0.1853741	R-SQUARE	0.0260
DEP MEAN	-0.600516	ADJ R-SQ	-0.0313
C.V.	-30.8691		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	-0.16978245	0.64033841	-0.265	0.7941
LMW	1	-0.07170117	0.10635724	-0.674	0.5093

Table B 3.7.8. Cross-Section Regression of Treated Coal Unit Data: 1977-1978 (IDC Excluded).

DEP VARIABLE: LCI84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.09369078	0.09369078	1.778	0.1910
ERROR	35	1.84384744	0.05268136		
C TOTAL	36	1.93753822			

ROOT MSE	0.2295242	R-SQUARE	0.0484
DEP MEAN	-0.61484	ADJ R-SQ	0.0212
C.V.	-37.3307		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	0.09750957	0.53549330	0.182	0.8566
LMW	1	-0.11581722	0.08684667	-1.334	0.1910

Table B 3.7.9. Cross-Section Regression of Treated Coal Unit Data: 1979-1980 (IDC Excluded).

DEP VARIABLE: LCI84KWD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.05556152	0.05556152	1.556	0.2292
ERROR	17	0.60712336	0.03571314		
C TOTAL	18	0.66268488			

ROOT MSE	0.1889792	R-SQUARE	0.0838
DEP MEAN	-0.616103	ADJ R-SQ	0.0300
C.V.	-30.6733		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	0.33209155	0.76142891	0.436	0.6682
LMW	1	-0.15384604	0.12334264	-1.247	0.2292

Table B 3.7.10. Cross-Section/Time-Series Pooled Regression for Nuclear Units: 1967-1977 (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	8	1.65371451	0.20671431	3.697	0.0071
ERROR	22	1.23000788	0.05590945		
C TOTAL	30	2.88372239			

ROOT MSE	0.2364518	R-SQUARE	0.5735
DEP MEAN	7.21847	ADJ R-SQ	0.4184
C.V.	3.27565		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD. ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	9.18180171	3.04393944	3.016	0.0064
LMW	1	-0.30342457	0.43582406	-0.696	0.4936
FIRST	1	0.27628884	0.09307343	2.969	0.0071
SOUTH	1	-0.21706347	0.12926398	-1.679	0.1073
E79	1	-0.14774333	0.26526545	-0.557	0.5832
D72	1	0.09367994	0.19763836	0.474	0.6402
D73	1	0.26284984	0.14916221	1.762	0.0919
D74	1	0.47289007	0.15841529	2.985	0.0068
D76	1	0.54024424	0.17736314	3.046	0.0059

Table B 3.8.1. Regression of Coal Units Partitioned by Capacity: 0-400 MW (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	10	2.07107677	0.20710768	3.622	0.0165
ERROR	13	0.74334696	0.05718054		
C TOTAL	23	2.81442374			

ROOT MSE	0.2391245	R-SQUARE	0.7359
DEP MEAN	6.671362	ADJ R-SQ	0.5327
C.V.	3.584343		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	6.75560037	1.15011551	5.874	0.0001
LMW	1	-0.03349763	0.19789223	-0.169	0.8682
FIRST	1	0.35915523	0.12242212	2.934	0.0116
SOUTH	1	-0.09185552	0.12655541	-0.726	0.4808
DFGD	1	0.16479644	0.10948092	1.505	0.1562
D74	1	-0.38685459	0.31206312	-1.240	0.2370
D75	1	-0.12683689	0.17726394	-0.716	0.4869
D76	1	-0.23716806	0.22481159	-1.055	0.3107
D77	1	-0.49889091	0.23253340	-2.145	0.0514
D78	1	-0.11260267	0.17145951	-0.657	0.5228
D79	1	0.03866571	0.27229365	0.142	0.8893

Table B 3.8.2. Regression of Coal Units Partitioned by Capacity: 401-600 MW (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	11	2.80389639	0.25489967	6.470	0.0001
ERROR	21	0.82728513	0.03939453		
C TOTAL	32	3.63118153			

ROOT MSE	0.1984806	R-SQUARE	0.7722
DEP MEAN	6.553324	ADJ R-SQ	0.6528
C.V.	3.0287		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	7.46162445	2.42144006	3.081	0.0057
LMW	1	-0.06652726	0.39661477	-0.168	0.8684
FIRST	1	0.36964901	0.07318752	5.051	0.0001
SOUTH	1	-0.18582537	0.10045283	-1.850	0.0785
DFGD	1	0.23894340	0.10353127	2.308	0.0313
D74	1	-0.74864109	0.24906288	-3.006	0.0067
D75	1	-0.62851721	0.26142632	-2.404	0.0255
D76	1	-0.63499054	0.27164551	-2.338	0.0294
D77	1	-0.74976787	0.24519596	-3.058	0.0060
D78	1	-0.78806518	0.24866017	-3.169	0.0046
D79	1	-0.41071709	0.24444960	-1.680	0.1077
D80	1	-0.61135994	0.24312387	-2.515	0.0201

Table B 3.8.3. Regression of Coal Units Partitioned by Capacity: 601-850 MW (IDC Excluded).

DEP VARIABLE: LCI84KW

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	12	3.26863165	0.27238597	4.340	0.0011
ERROR	24	1.50612546	0.06275523		
C TOTAL	36	4.77475711			

ROOT MSE	0.2505099	R-SQUARE	0.6846
DEP MEAN	6.522634	ADJ R-SQ	0.5268
C.V.	3.840625		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	11.20525011	3.73058056	3.004	0.0062
LMW	1	-0.77802293	0.57216071	-1.360	0.1865
FIRST	1	0.28251882	0.10312976	2.739	0.0114
SOUTH	1	-0.04589613	0.10297936	-0.446	0.6598
DFGD	1	-0.06765379	0.14689090	-0.461	0.6493
D74	1	0.16519862	0.18867213	0.876	0.3899
D75	1	-0.01314991	0.32881380	-0.040	0.9684
D76	1	0.28651055	0.26023844	1.101	0.2818
D77	1	0.10045249	0.21336579	0.471	0.6420
D78	1	0.31621484	0.17498797	1.807	0.0833
D79	1	0.41168145	0.21081740	1.953	0.0626
D80	1	0.91185785	0.34043395	2.679	0.0131
D81	1	0.67813825	0.23028944	2.945	0.0071

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