

To the Graduate Council:

I am submitting herewith a dissertation written by Raul Smith-Fontana entitled "A General Equilibrium Model to Forecast Market Penetration of Energy Supply Technologies." I have examined the final copy of this dissertation for form and content and recommended that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Engineering Science.

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A GENERAL EQUILIBRIUM MODEL
TO FORECAST MARKET PENETRATION
OF ENERGY SUPPLY TECHNOLOGIES

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Raul Smith-Fontana

March 1987

DEDICATED

To My Wife, Maria Luisa

To My Sons & Daugther, Raul, Alejandro, Javier & Maria Luisa

To My Late Father, Raul

To My Mother, Estrella

ABSTRACT

Energy supply is a preoccupation of planners, managers and government. Energy demand is a fact of society.

Dynamic relations between energy supply and demand are difficult to establish in the long run and even in the short run. Prices of fuels and their availability in specific regions are the main driving elements to determine investment in energy generation.

A model to forecast market penetration of energy supply technologies is presented here. The model is a general equilibrium end-use energy type model that simulates energy supply and energy demand in the context of the whole economy of a country. Given base year input-output coefficients, the composition of final demand, bounds for energy generation and prices for capital and labor; the model determines the level of operation and optimum prices for fuel and services.

The dynamics are simulated forecasting the input-output coefficients for the energy demand sectors by two lag equations which relates the energy demand and the total demand with the optimum prices of fuels, demand sectors and capital and labor by means of two logit functions and a constant elasticity of substitution function.

The model is validated using U.S. energy supply-demand data over the years 1961 to 1985 for ten energy sectors. The base year is 1977 and bench-reference years are 1961, 1974 and 1985.

ACKNOWLEDGMENTS

I wish to thank the faculty of the Industrial Engineering Department for their individual contribution's to my education.

Special gratitude is owed to the Industrial Department Head, Dr. John N. Snider, for his participation in my program and to Dr. Elden L. DePorter and Dr. Charles H. Aiken for giving me the opportunity in a special topic course to approach the basis for this dissertation.

I would also like to extend my sincere gratitude to the Dean of the College of Engineering, Dr. William T. Snyder, for his understanding and support of my doctoral program.

A special note of gratitude is extended to the Vice Provost and Dean of the Graduate School, Dr. C. W. Minkel, for his support and encouragement since the initiation of my program.

I would like to express my appreciation to the Chancellor Dr. Jack E. Reese, and his Executive Assistant, Dr. Donald R. Eastman, for their friendship and continuous understanding of my goals.

I am indebted to Dr. Charles E. Whittle, the Director of the Institute of Energy Analysis of Oak Ridge Associated Universities for providing motivation and inspiration and for his friendship and generosity in permitting the use of the

Institute's library.

I would like to thank the members of my committee:
Dr. John M. Holmes, Professor of the Chemical Engineering;
Dr. Robert A. Bohm and Dr. Henry W. Herzog, Professors of
Economics; and Dr. William G. Sullivan, Professor of Industrial Engineering and Director of the Computer Integrated Engineering and Manufacturing Center, for their support in my work.

I owe a large debt of gratitude to my committee chairman, Dr. George C. Frazier, for his personal involvement and to my adviser Dr. David B. Reister of Oak Ridge National Laboratory for his wise guidance and for the many hours he spent in teaching me the fascinating art-engineering of energy modeling.

Finally, I would like to express special words of gratitude to the University of Santiago of Chile which sponsored and financially supported my doctoral program.

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LIST OF SYMBOLS

X	Vector of input levels
t	Time
$F(X)$	Production function
$F(X,t)$	Time-dependent production function
Y	Amount of output
P	Vector input price
P^T	Transpose price vector
$G(Y;P)$	Producer's total minimum cost function
G_{P_i}	Partial derivative of G with respect to P_i
$C(P)$	Unit cost function
$C(P,t)$	Time-dependent unit cost function
C_{P_i}	Partial derivative of C with respect to P_i
a_i	Input-output coefficient describing the amount of input X_i per unit of output Y
s_i	Cost share fraction of the cost of production which is paid to each factor
σ_{ij}	Demand elasticity, percentage change in the price of one factor to the percentage change in the demand for another factor
ϵ_{ij}	Share elasticity, percentage change in the price of one factor to the percentage change in the cost share for another factor
$\ln$	Natural logarithm
$[\cdot]_{\cdot j}$	Partial derivative of variable $\cdot_i$ with respect to variable $\cdot_j$
δ_{ij}	Delta function
$f(u)$	Weibull distribution
u_j	Price of energy service from fuel option j
δ_j	Average cost of energy from fuel option j (scale parameter)
τ	Broadness of the distribution (shape parameter)
p_j	Average cost of energy service
Γ	Gamma function
N	Number of sectors (goods, services, factors)
M	Number of processes (industries)
B_{ij}	Input vector (input of good i to a unit of operation of process j)
A_{ij}	Output vector (output of good i from a unit of operation of process j)
D_{ij}	Net output vector
X_j	Level of operation (production)
Z_j	Constraint on level of operation
P_K	Price of capital
P_L	Price of labor
TX_j	Tax
V_j	Value added for processes
V	Value added
T	Total cost of production
R	Total revenue of production
Y_i	Composition of final demand
P_i	Optimum prices for fuel, services and factors
π_j	Excess of profit

YA_i	Final demand share for each sector
YA_i^*	Optimum final demand share for each sector
β	Coefficient for the logit final demand share function
v	Exponent for the logit final demand share function
YT	Gross National Product
δ	Lag parameter for final demand
AIF	Engineering-economic-energy coefficients
PI	Fuel option prices
AM	Fuel option shares
PN	Average costs of energy
AN	Average energy consumption
PP	Indexed prices
BP	Base prices
α	Coefficients for the CES function
p	Substitution parameter for the CES function
ϵ	Elasticity parameter for the CES function
AS	Partial derivative of the cost function
B_{ij}^*	Optimum demand input coefficients
μ_j	Lag parameter for each process
E	Electricity
CO	Crude oil
NG/W	Natural gas well
NG/T	Natural gas transported
NG/D	Natural gas distributed
FO/L	Fuel oil light
FO/H	Fuel oil heavy
LPG	Liquefied petroleum gas
C	Coal
W	Wood

CHAPTER 1

INTRODUCTION

1.1 Origin of the Dissertation

This dissertation research was initially started to develop an economic-industrial-energy model specifically for Chile that could elaborate on the industrial sector and obtain some end-use energy-price relations for Chile. However, limitations on the availability of economic and energy data for Chile made it impossible to carry out a reasonable validation of such a model.

Since a model of such characteristics would be of great importance to Chile and to any other developing country and since the process of obtaining adequate and consistent data is a long-term and complex effort, it was decided that an appropriate model would be structured which could use U.S. data as much as reasonably possible for validating the model. Under these circumstances the model should be developed having a "compromise structure" which could later be adapted to accommodate the attributes of countries with other energy systems such as those of Chile.

Probably some of the global and end-use energy results developed here will not be completely new for the USA, since a wide and consistent research program has been done in this

area by several researchers and institutions. On the other hand, hopefully, the new model will be a useful tool that can be used, with appropriate data and minor changes in the structure, to interpret energy-price interactions and to envision related policies for developing countries.

The conceptual part of this research was initiated under a cooperative agreement between the Institute of Energy Analysis of Oak Ridge Associated Universities and the College of Engineering of the University of Santiago of Chile and was based on a preliminary sketch of an economic-energy model for Chile presented at the II Interuniversity Energy Symposium in November 1983 by the University of Santiago of Chile.

1.2 Energy Modeling Philosophy

Energy modeling is a methodology of applied science relying on systems analysis, process engineering, process economics and of course on the use of computers. A model of an energy system is based on many possible hypotheses about the behavior of the components of that system. The validation of such a causal model must be carried out with a full awareness of the nonexperimental nature of the observations of the system. Statistical analysis is a necessary method for testing a model, but the validation of the system model must also rest on the plausibility of its a priori theoretical base.

The development of fuel supply projections for a particular economy is a complex task because of the interactions

of numerous engineering, economic, social and political elements, most of which are uncertain or unknown at a given moment in time.

The short-term rate of energy reserves depletion and the relative use rates of different fuels can be estimated and based on facilities' capacities. In the long run, reserve depletion depends on the integrated demand curve and the cumulative discovery rates. These rates will depend on exploration activities which reflect prices, price projections and capital availability. Furthermore, these factors interact with the rate of development and commercial applications of new energy related-technologies, which in turn depend, in part, on fuel prices and their anticipated trends.

Choosing the fuel which will be economic for a given application over the near-to long-range future is difficult, because the extent of the available natural energy resource, the adjustment of its price, and the need for imports may not be easily predicted.

Many fuels compete for the same market, just as many market sectors compete for the same fuel. It is a fact that all fuels available tend to be used, to some extent at least, in spite of what appear to be price differentials. The prediction of the price which a given fuel will command in the marketplace is a task which requires extensive knowledge of supply, demand, capital and labor, which are the ingredients of Gross National Product.

Sensitivity of fuel prices to production based on new technologies, including the substitution of one fuel for another, is another important element that influences the time-table for the introduction of new technologies into the production of energy.

CHAPTER 2

OBJECTIVE, ACTIVITIES, SCOPE AND LIMITATIONS

We can envision a very high objective, we can plan a broad range of activities, but we need to be pragmatic about the limitations of the real world. This chapter intends to focus on these aspects and make them compatible with the involvement of this dissertation.

2.1 Objective and Purpose

The primary objective of this dissertation is to develop a conceptual structure, find the appropriate data for such structure and modify existing codes [3] for implementing a model suitable for forecasting market penetration of energy supply technologies in a given country. The model will be suitable as a computational analytical tool for government policy for planning and analysis, for managerial decision-making and for educational research activities.

The primary purpose is to focus on market penetration applications and to compare uses of gas versus electricity in the residential and commercial sectors, of gas/oil versus electricity in the industrial sector, of gas/oil versus electricity in the transportation sector and of coal versus nuclear in the electricity generation sector.

There are numerous dimensions to energy-economic interactions which deserve attention, since energy is an important input in virtually all economic activities. Among the most important issues are the impact of energy cost on aggregate growth and its sectoral composition, the relationships between energy imports, investments rates, the balance of payments, the scope for substitution, and the effect of energy prices on income distribution and employment. If there were an "ideal" model to represent all these factors in a dynamic way, it would be disaggregated into many sectors of production with endogenous factor substitutions, have many consumers with different factor endowments and consumption behavior, contain a complete set of fiscal accounts, include foreign borrowing opportunities, and embody efficient rules for generation of saving and allocation of investment. While theoretical models could be formulated with these characteristics, in practice no single model could serve all these diverse purposes. Hence, this particular work has focused on those attributes stated in the objective and purpose above.

2.2 General Activities

The preliminary activities of this research were carried out as follows:

- Review of related literature on energy models:

References [1-24].

- Review of related literature on the U.S. energy end-use models and input-output analysis: References [30-41].

- Analysis of the U.S. economic and energy data from 1960 to 1985: References [50-79].

- Review of the economic theory of production and cost function, and theory of choice: References [80-93].

- Analysis of the Chilean economic and energy data from 1960 to 1984: References [100-103].

The subsequent research activities were carried out and organized according to the following topics:

- Conceptual development of model structure
- Data development and structuring
- Computing codes modification and structuring
- Validation of the model
- Interpretation of results

2.3 Scope and Limitations

The General Equilibrium Model (GEM) developed here uses the best features of the Oak Ridge Industrial Model (ORIM) [1], the Hudson and Jorgenson Model [2] and the preliminary Economic and Energy Model for Chile [3].

There are several other models that, to some extent, were also considered in developing the structure of the GEM:

- The Regional Demand Forecasting Model (RDFOR) [4]

- The Industrial Sector Technology Use Model (ISTUM) [5]
- The Industrial Fuel Choice Analysis Model (IFCAM) [6]
- The Brookhaven National Laboratory Integrated Model [7]
- The Argonne National Laboratory Models [8]
- The Interindustry Forecasting at the University of Maryland Model (INFORUM) [9].

In general, for these models the available data are more consistent in energy quantities than in energy prices. The main concern about energy's role in the economy only started in 1974 with the energy crisis.

A major limitation of energy models is the selection of the endogenous and exogenous variables based on the assumption that acceptable data are available for these variables.

Another limitation is that we assume that the system will allow perfect economic competition in a perfect market.

2.3.1 Area of research

The research described here is within the area of energy demand models, in particular those demand models of the end-use type between the economy-wide optimization models and the computable general equilibrium models. This area of research is supported by solid theoretical foundations of general equilibrium and dynamic structures, optimization and economic theory.

2.3.2 State of the art in the area

The Oak Ridge Industrial Model [1] is structured around the principle of cost function/production function duality and a logit function which is defined later. In concept, the model characterizes each industry as a production function where capital, labor, material and energy services are combined to produce the required quantities of industrial output in each forecast year.

The Hudson-Jorgenson Model [2] is a quantitative approach to U.S. energy policy analysis, based on integration of econometric modeling and input-output analysis. The model consists of production models for nine economic sectors, a model of consumer demand and a macro-econometric growth model for the U.S. economy.

The Economic and Energy Model for Chile [3] is a general equilibrium model that simulates both energy supply and energy demand in the context of the whole economy. In particular fuel is consumed by the Industrial, Transportation, Services and Import sectors to provide energy services. Import is considered as import minus export.

2.3.3 Research contribution in the area

The GEM whose objective and purpose were mentioned before, has been developed based on [1], [2] and [3].

The research generates a new model structure with the capability of forecasting energy end-use for the whole

economy of a country as in [3], will correct some limitations observed in [2] by using the Constant Elasticity of Substitution (CES) cost function instead of the Translog cost function to represent energy conservation, and will use a Logit cost distribution function as in [1] for the behavioral analysis to represent the market share for the options that provide energy services.

CHAPTER 3

FUNDAMENTALS

The fundamentals of mathematics and economics together with the art-engineering of interpreting the theories and designing models to represent a particular reality are summarized by the concepts of production/cost duality, model specification and consumer behavior.

3.1 The Production Function (The Primal)

In economic theory the production function is a mathematical statement relating quantitatively the pure technological relationship between the output of a process and the input factors of production. Its main purpose is to explore the possibilities of substitution between the factors of production to achieve a given output.

The distinct kind of goods and services that are usable in a production technology are referred to as the factors of production for that technology; and for any set of inputs of these factors, the production function yields the maximum output.

The production function is ideally a statement of purely technological alternatives, without regard to their execution and one could define different production functions for short-run or long-run economies. However, institutional

conditions of specific economic planning must be brought into the definition, and this confuses the purely technological character of the production function.

In general, the production function is regarded as a mathematical construction for well-defined production technologies. These technologies consist of a family of conceivable and feasible engineering arrangements, which are necessarily restricted to particular schemes found in practice, but can span historical changes in the application of new technologies.

Once defined, the technology implies a certain set of factors of production and no limitation should be put upon the inputs of these factors as to type and amount available. Such limitations merely prescribe a particular realization of a technology which may be considered by imposing constraints to the input flows who does restrict the analysis to a particular subset of the factor input space.

If the production function is to define purely technological possibilities, the available means of a firm or of other production units is not relevant.

3.2 The Cost Function (The Dual)

An alternative approach to the production theory is to start directly from observed economic data (supply, demand, prices, cost and profit). The advantage of such an approach is that the theory can be formulated directly in terms of the

causal economic relationship that is presumed to hold, without the intervening constructive steps required in the traditional theory.

Because this approach is not bound by computational tractability in going from production technology to economic observation, the prospect is opened for more satisfactory models of complex production problems.

It would at first appear that a theory of production couched in terms of economic observables would be less fundamental than one based on the physical technology, and that one could never be sure of an economic theory consistent with a physical model. However, the theory of production duality establishes that the two approaches are equivalent.

Using duality, the technology underlying an economic model can be reconstructed and tested for compatibility with physical laws, as necessary. Then, the main thrust of the analysis can be devoted to developing the structure and relations of observed economic variables.

In the classical theory of production, the firm is assumed to face fixed technological possibilities and a competitive input market, and must choose an input bundle to minimize the cost of producing each possible output. For fixed input prices, this behavior determines minimum cost as a function of output.

A generalization allows input prices to vary and considers minimum cost as a function of both input prices and

output. With this insight, the cost function becomes a powerful analytic tool in the theory of production, particularly in economic applications.

The principal practical advantage of the cost function lies in its computationally simple relationship to the cost minimization input demand function: the partial derivatives of the cost function with respect to input prices yield the corresponding input demand functions, and the sum of the values of the input demand equal cost.

The definition of the cost function as the result of an optimization yields strong mathematical properties, and establishes the cost function as a sufficient representative for all the economically relevant characteristics of the underlying technology.

3.3 Primal and Dual Theory (References:[80],[83])

The aim of the duality discussed here is to display a dual determination of production and cost structure and to provide explicit dual calculation of functions which define these structures. The classical production function is not a direct dual of the classical cost function (factor minimal cost). Instead the distance function of the production structure (price minimal cost function) is the dual of the classical cost function. However, the production function $F(X)$ and the cost function $G(Y;P)$ are uniquely determined from each other.

(1) Definition : $Y=F(X_1, X_2, \dots, X_n)=F(X)$

where: F is an N factor production function

Y is the maximal amount of output

which can be produced during a

given period of time using

X_i units of input $i=1, 2, \dots, N$

X vector of input levels

(2) Assumptions:

$F(X) > 0$, for all $X_i > 0$: A positive amount of output can be produced from a vector of positive amount for each input.

$F(kX) = kF(X)$, for all $k > 0$: F is homogeneous of degree $X_i > 0$ one, the technology exhibits constant return to scale.

$F(kX' + (1-k)X^{\sim}) \geq kF(X') + (1-k)F(X^{\sim})$, for all

$X_i', X_i^{\sim} > 0$; $0 \leq k \leq 1$

F concave, the technology

exhibits a non-increasing

marginal rate of substitution.

(3) Definition : If the production function $F(X)$ satisfies certain regularity conditions, then the producer's total minimum cost function

$G(Y; P_1, P_2, \dots, P_N) = G(Y; P)$

can be calculated as the solution to

the following minimization problem

$G(Y; P) = \text{MIN}\{P^T X : F(X) \geq Y, X_i \geq 0\}$

where $P=(P_1, P_2, \dots, P_N)$ is the
vector input price.

Thus, the producers take prices as given and attempt to minimize the cost of producing a specified output Y .

In general, the total cost G depends on:

Y the chosen output level

P the given input prices

F the given product function

(4) Theorem : (Samuelson-Shephard Duality)

If the production function $F(X)$ defined in

(1) satisfies positiveness, homogeneity

and concavity assumed in (2), then for

$Y > 0$ and $P_i \geq 0$ the cost function $G(Y; P)$

defined in (3) takes the factor form

$$G(Y; P) = C(P)Y$$

where : $C(P)$ is the unit cost function and

satisfies (2).

Thus, a production function F which satisfies (2) has a unit cost function C which also satisfies (2).

It is known that a production function $F(X)$ determines a cost function $G(Y; P)$; what is not well known is the converse, that a cost function satisfying certain regularity conditions determines a production function. That is, there is a duality between the cost and production functions.

We now show how a unit cost function $C(P)$ satisfying (2) may be used in order to define a production function.

(5) Definition : If the unit cost function $C(P)$ satisfies (2)

then the function $F^*(X')$ defined by

$$F^*(X') = \text{MAX}\{Y : C(P)Y \leq P^T X' \text{ , all } P_i \geq 0\}$$

also satisfies (2) where :

$$X' = (X_1', X_2', \dots, X_N')$$

is a given vector of input.

Thus, $F^*(X')$ can be interpreted as a production function.

The above constrained maximization problem has an infinite number of constraints, and the envelope of production possibilities for Y will generate the true $F(X)$ having the same properties as $F^*(X')$.

(6) Definition : The production function $F^*(X')$ defined

in (5) is equivalent to:

$$F^*(X') = [\text{MAX}\{C(P) : P^T X' = 1, P_i \geq 0\}]^{-1}$$

Thus, the production function is expressed as the solution to a simple constrained maximization problem involving the unit cost function.

(7) Theorem : Let the unit cost function C satisfy (2).

Consider a production function $F^*(X')$

defined by (6).

Define the unit cost function $C^*(P)$ generated by $F^*(X')$ for $P_i \geq 0$ as:

$$C^*(P) = \text{MIN}\{P^T X : F^*(X) \geq 1 \text{ , } X_i \geq 0\}$$

Then for every $P_i^* > 0$ we have

$$C(P^*) = C^*(P^*)$$

Thus, the production function $F^*(X')$, which was defined

by the original unit cost $C(P)$ has a unit cost function $C^*(P^*)$ which coincides with $C(P^*)$.

The following result makes the duality theory a extremely useful tool in empirical applications.

(8) Lemma : (Shephard)

If the unit cost function $C(P)$ satisfies (2) and, in addition, is differentiable with respect to input price at the point $P_i^* \geq 0$, then :

$$Y C_{P_i}(P^*) = X_i(Y; P^*) \quad \text{all } i$$

where : X_i is the cost minimizing quantity of inputs i needed to produce Y unit of output given input price P^* where the underlying production function $F^*(X')$ is defined by (5) or (6).

C_{P_i} is the partial derivative of C with respect to the price P_i .

The proofs of the theorems and lemma can be found in [81] and [83]. The assumption (2) and regularity conditions for $F(X)$ and $G(Y; P)$ may vary.

Thus, considering the definition (3) and lemma (8), there are at least two distinct methods of deriving a system of cost minimizing input demand functions X_i . One method is to postulate a functional form for a production function $F(X)$ satisfying assumption (2) and then use Lagrangian or mathematical programming techniques in order to

solve the cost minimization problem:

$$\text{MIN } \{ P^T X : F(X) \geq Y, X_i \geq 0 \}$$

The second method is to postulate a differentiable functional form for a unit cost function $C(P)$ satisfying assumption (2) and thereby to obtain the derivative demand function $X_i(Y;P)$ by differentiation

$$C_{P_i}(P) = X_i/Y = a_i$$

where : a_i are the input-output coefficients describing the amount of input X_i per unit of output Y .

The difficulty with the former method is that if we take a flexible functional form for $F(X)$, as defined later, then it is usually impossible to obtain the derived demand functions $X_i(Y;P)$ as explicit functions of the unknown parameters of $F(X)$.

3.4 Production-Cost Function Properties (Reference:[1])

Consider an existing factory (firm, industry) which produces output Y from a vector of physical inputs X .

The outputs and inputs can be measured in physical units or value units; Input-Output coefficients a_i are the amount of input X_i per unit of output Y .

$$(9) \quad a_i = X_i/Y$$

A basic economic identity is that revenues from sales minus payment to the factors of production other than capital (labor, energy and material) are equal to before-tax profit.

If we consider profits to be payments to the factor of

production capital, then total sales are equal to total factor payment

$$(10) \quad CY = \sum P_i X_i$$

where: C is the price of output Y

P_i is the price of input X_i

Clearly using (9) we get

$$(11) \quad C = \sum P_i a_i$$

The price of output C, is equal to the unit cost of production.

A typical industry transforms input (capital, labor, energy, material) into an output. The production function relates the maximum output, Y, to any given vector of input, X, that is

$$(12) \quad Y = F(X, t)$$

where: t is time, which indicates that the maximum output from a given set of inputs can change with time.

Technological change can increase the maximum output. Natural resources exhaustion, or environmental constraints or policies can decrease the maximum output.

Given a production function and a price vector, one can select the combination of production factors that have the lowest unit cost.

The result of this optimization process is a least cost set of input-output coefficients, which depends on the price vector and the current technology.

The unit cost of production (11) depends on the prices and the input-output coefficients.

The optimum set of input-output coefficients is determined by the prices. Thus, the minimum cost production depends on the price alone, that is

$$(13) \quad C = G(P, t)$$

F and G share the Primal-Dual Properties.

Next, there is a list of definitions, properties and characteristics of the cost function G:

$$(14) \text{ Optimum Input-Output coefficients : } a_i = G_{pi}$$

$$(15) \text{ Cost share : } s_i = (P_i a_i)/C, \quad \sum s_i = 1$$

$$(16) \text{ Price elasticity of demand :}$$

$$\sigma_{ij} = (P_j/a_i)[a_i]_{P_j} = [Lna_i]_{LnP_j}$$

$$s_i \sigma_{ij} = s_j \sigma_{ji}$$

where : $[a_i]_{P_j}$ represent the partial derivative of functions a_i with respect to the prices P_j .

$$(17) \text{ Share elasticity :}$$

$$\epsilon_{ij} = (P_j/s_i)[s_i]_{P_j} = [Lns_i]_{LnP_j}$$

$$(18) \text{ Homogeneity :}$$

$$G \text{ homogeneous on } P \text{ of degree } 1 \quad G(kP, t) = kG(P, t)$$

$$a_i \text{ homogeneous on } P \text{ of degree } 0$$

$$a_i = G_{pi}(kP, t) = k^0 G_{pi}(P, t)$$

$$= G_{pi}(P, t)$$

$$\text{From Euler's homogeneity property, } \sum \sigma_{ij} = 0$$

(19) Relationship between demand elasticity and share elasticity :

$$s_j = [\text{Ln}G]_{\text{Ln}P_j}$$

$$\epsilon_{ij} = \delta_{ij} + \sigma_{ij} - s_j, \quad \delta_{ij} = 1 \text{ if } i=j$$

$$= 0 \text{ if } i \neq j$$

3.5 Model Specification (References:[1],[85])

The use of the theory requires that the model allow the choice of a function from a large family of possible functions.

In order to analyze different functions we need first to call attention to the definition of "flexible form" and state that the selection of the cost function $G(P,t)$ should be of such a form as required by the model specification.

(20) Definition : A function $F(X)$ or $G(Y;P)$, production or cost function, is of flexible form if it has enough degrees of freedom so that it can match an arbitrary set of parameters

s_i : Cost share

σ_{ij} : Demand elasticity, in the base year of the study period; or more generally, if it is capable of providing a second order approximation to an arbitrary production function which satisfies (2).

Several cost functions have been developed and applied to different models. Some of those are of flexible form, some

are not. In applying the above definition, one may assume that the prices are price indexes, which are equal to unity in the base year, and then find the relationships between the parameters of the functions and a_i , s_i , σ_{ij} and ϵ_{ij} .

(21) Leontief function :

$$G = \alpha_0 \sum \alpha_i P_i \quad \sum \alpha_i = 1$$

(22) Cobb-Douglas function:

$$G = \pi \prod P_j^{\alpha_j} \quad \sum \alpha_j = 1$$

(23) Translog function :

$$\begin{aligned} \ln G &= \sum \phi_i \ln P_i + (1/2) \sum \sum \phi_{ij} \ln P_i \ln P_j \quad \sum \phi_i = 1 \\ &\quad \sum \phi_{ij} = \sum \phi_{ji} = 0 \end{aligned}$$

(24) Constant Elasticity of Substitution function (CES)

$$G = [\sum \alpha_i P_i^p]^{1/p} \quad \sum \alpha_i = 1$$

(25) Generalized Constant Elasticity of Substitution function (GCES) :

$$\begin{aligned} G &= [\sum \alpha_i g_i^p]^{1/p} & g_i &= [\sum \beta_{ij} P_j^{q_i}]^{1/q_i} \\ \sum \alpha_i &= 1, \quad \alpha_i \geq 0 & \sum \beta_{ij} &= 1, \quad \beta_{ij} \geq 0 \\ p &\leq 1 & q_i &\leq 1 \end{aligned}$$

The GCES function can be written also as:

$$G = [\sum \alpha_i (\sum \beta_{ij} P_j^{q_i})^{p/q_i}]^{1/p}$$

This two-level cost function corresponds to a two-stage production process.

In the first stage, factors are used to produce intermediate goods; in the second stage, the intermediate goods are used to produce final output.

The variables and parameters are defined as follows:

g_i is the cost of each intermediate good,
 α_i, β_{ij} are parameters; base year cost shares for
 output and the intermediate goods,
 p, q_i are parameters to control the price response
 for trade-offs between factors at the output
 level and at the intermediate good level,
 G is the final output cost.

The analysis and definition of flexible form applied to the cost functions give us the following result

- (21), (22) are not of flexible form
- (23), (25) are of flexible form
- (24) is not of flexible form, unless depend
on two factors of production.

Several criteria can be considered in choosing functional forms .

First, one tends to choose a simple form rather than a complicated form if the two can explain the problem equally well. Linearity, in general, tends to give satisfactory results.

Second, one should rely on economic theory in choosing functional forms.

Third, one should look for a model with good predictive power. The functional form should have a close fit to data as a necessary condition to predict well.

An operational approach to the selection of an appropriate production function must recognize the limitations

imposed on our knowledge by observability and measurability of variables and by the relationship defining production functions.

Another important limitation on our knowledge arises through technological changes. If technological changes cannot be observed directly, we must rule out their disturbing effects on the observed production relationship by appropriate assumptions and postulate that certain observed relationships are invariant under technological changes.

Depending on what we assume to be observable, we are restricted to some sub-class of admissible production functions. Further restrictions are imposed by the limitation of statistical techniques. In practice, most estimated relationships are assumed linear in the variables or in some suitable transformation of functions.

3.6 Theory of Choice. The Logit Function (Ref:[1],[85])

Many empirically important decisions involve choice among alternatives.

The problem of economic-discrete choice parallels the decision context in which psychophysical models have been applied successfully.

If the individual demand is the result of utility maximization by a representative consumer whose decision variable is continuous, conventional marginal analysis applies.

This single representative consumer model may be a useful analytic device under appropriate assumptions.

A probabilistic choice system could be defined describing the observable distribution of demand. Under the hypothesis of random preference maximization, which postulates that the distribution of demands in a population is the result of individual preference maximization, and assuming sufficient integrability condition for an observed demand distribution to be consistent with a distribution of preferences, several functional forms have been derived for a probabilistic choice system; in particular three major families are the Probit, the Logit and the Elimination.

In the Probit forms the utility levels of the alternatives are normally distributed, the Logit forms uses a Weibull distribution, and the Elimination forms are defined by transition probabilities.

3.6.1 Fuel-share Models

A fuel-share model, in which all options have a partial share of the market, and market shares change continuously in response to price change, can be considered as a Logit function $f(u)$ based on the Weibull distribution.

Consider the distribution $f(u)=f(u_1, \dots, u_K) \geq 0$

$$\int_0^\infty f(u) du = 1$$

Probability that the price of energy service is in the region du about u , where: $f(u) = \pi(\tau/\delta_j)(u_j/\delta_j)^{\tau-1} \text{Exp}\{-(u_j/\delta_j)^\tau\}$

and; u_j Price of energy service from option j

δ_j Average cost of energy fuel from option j (scale)

τ Broadness parameter of the distribution (shape)

Let p_j : Average cost of energy service

$$p_j = \int_0^\infty u_j f(u_j) du_j$$

$$p_j = \int_0^\infty u_j (\tau/\delta_j) (u_j/\delta_j)^{\tau-1} \text{Exp}\{-(u_j/\delta_j)^\tau\} du_j$$

$$p_j = \delta_j \Gamma(1+1/\tau)$$

where: δ_j, τ determines the average cost for each energy service and Γ is the Gamma function.

also, as τ large, $\Gamma(1+1/\tau) \rightarrow \Gamma(1)=1 \implies p_j \approx \delta_j$

Under the assumption that reordering the options are equivalent in terms of management decision (integrability condition), or managers make a rational decision choosing the least cost option in a competitive market;

let a_j : market-share of option j .

$$a_1 = P(0 \leq u_1 \leq \infty, u_1 \leq u_2 \leq \infty, \dots, u_1 \leq u_K \leq \infty)$$

.....

$$a_K = P(0 \leq u_K \leq \infty, u_K \leq u_1 \leq \infty, \dots, u_K \leq u_{K-1} \leq \infty)$$

consider

$$a_1 = \int_0^\infty (\tau/\delta_1) (u_1/\delta_1)^{\tau-1} \text{Exp}\{-(u_1/\delta_1)^\tau\} du_1 \dots \dots \dots$$

$$\dots \dots \dots \int_{u_1}^\infty (\tau/\delta_K) (u_K/\delta_K)^{\tau-1} \text{Exp}\{-(u_K/\delta_K)^\tau\} du_K$$

$$\text{Let } h_j = \int_{u_1}^\infty (\tau/\delta_j) (u_j/\delta_j)^{\tau-1} \text{Exp}\{-(u_j/\delta_j)^\tau\} du_j = \text{Exp}\{-(u_1/\delta_j)^\tau\}$$

then

$$a_1 = \int_0^\infty (\tau/\delta_1) (u_1/\delta_1)^{\tau-1} \text{Exp}\{-\sum (u_1/\delta_j)^\tau\} du_j = \delta_1^{-\tau} [\sum \delta_j^{-\tau}]^{-1}$$

For large τ $p_j \approx \delta_j$

and for all τ $a_1 = p_1^{-\tau} [\sum p_j^{-\tau}]^{-1}$

CHAPTER 4

MODELS BACKGROUND

The concept of energy demand is a crucial aspect in the understanding and design of energy models. A summary view of different methodologies used in energy modeling is considered next to represent the general tendencies in the interpretation of the energy demand concept. The equilibrium model tendency is the framework for this dissertation.

4.1 The Energy Demand Concept

It is normally assumed that consumers seek to allocate expenditure of income among available commodities (fuel) in order to obtain the maximum degree of satisfaction from total expenditure, while producers demand energy inputs in relation to other factors of production in order to minimize the total cost of producing a given amount of goods. This difference in motivation means that an energy analysis of the residential, commercial, industrial and transportation sectors should be treated separately but under the same framework.

The fact that energy products are not consumed for their own sake, but in conjunction with energy-using equipment for the services provided, gives rise to two major issues in modeling demand.

First, the demand for a specific fuel interrelates with

the demand for end-use services and the demand for associated fuel-using equipment. The demand for each fuel depends on the total demand for services and the choice of fuel-using equipment, the demand for services depends on their costs and the demand for fuel-specific equipment depends, on equipment prices and on relative operation costs.

"Prices both determine and are determined by decisions made at each stage."

There is, in other words, an interrelationship among various fuel prices, characteristics of stocks of fuel-using equipment and the amount of each fuel consumed.

Focusing attention on this causal chain, the task of developing a model of the system can be undertaken.

Second, the demand for fuel is time oriented. Consumers are limited in their ability to respond immediately to a price change. Individuals reside in houses with a given array of appliances of given efficiency and possess a given set of consumption habits. Their immediate response to a price change is limited to more or less use of available energy-using devices.

Over a longer period of time, individuals may alter their stock of energy-using equipment, but only when the fuel price has increased enough to make the changes worthwhile (normal replacement). New residences and new equipment purchases will reflect the changes in energy prices and will combine with replacement purchases to alter the stock.

Industries are more locked than residences into existing capital structures and production processes. This limits their response to energy price changes to more or less intensive use of existing capital.

As new plants are constructed, new industrial processes can be considered, or existing equipment replaced, and this gives firms a wider range of options with which to respond to the price change.

Both individuals and firms, being part of the residential, commercial and the industrial sectors, own transportation devices which again are capital stock and fuel-tied. In this case we need to consider another sector, the transportation sector.

Thus, the initial, or short-run, response to a price change is only a partial response, and the total response may be expected to accumulate over time.

Prices, fuel demands and capital stocks are important aspects of the dynamics of energy demand and should be given special considerations in energy modeling.

4.2 A Classification of Models (References: [10],[16])

There are several alternative methodologies for energy modeling that could serve policy planners, decision makers and educators.

It is not easy to classify those methodologies and establish strict boundaries, but with regard to different

analytical techniques, it is possible to specify some types of models. These are project evaluation, technology assesment, energy assesment, macro-simulation models, economy-wide optimization models and general equilibrium models. Within each type of model there exist variations in details of structure.

4.2.1 Project Evaluation

The most basic policy problem is that of deciding whether to devote resources to a particular energy project. There are standard ways of dealing with this, which do not deal with the difficult but often central problem of determining the correct shadow prices, including the shadow discount rate, which correctly evaluates the real social cost of the resources to be used and the outputs. This methodology does not often consider in an adequate manner the rest of the economy, with respect to inter-temporal decisions and often concentrates on the particular project. No typical example will be mentioned here since this is a well-known family of models that normally handle uncertainty connected with the cash flow of projects under various assumptions to obtain the expected utility.

4.2.2 Technology Assesment

Given the energy demand forecast for a single sector,

this type of model finds the optimum mix of energy projects that will satisfy that demand.

It usually minimizes total cost of the energy sector, allocates resources and makes technological choices using an "energy reference system". Normally it overstates the potential rearrangement which is desirable, as well as the desirability of some new projects.

A particular example of this type could be the Brookhaven Energy System Optimization Model [7].

4.2.3 Energy Assessment

These studies typically include detailed investigation of particular features of the energy-producing sectors and the particular areas of demand as well as analysis of policy approaches to specific problems. They are not comprehensive and not necessarily consistent, therefore cannot take into account the interactions between the energy sector and the rest of the economy.

A typical example of this category could be the Cooperative Energy Assessment between the U.S. and the Republic of Korea developed by the Argonne National Laboratory [8].

4.2.4 Macro-simulation Models

These type of models cover the entire economy and generate forecasts of aggregate variables as well as energy sector

variables. They typically distinguish from a few to a substantial number of sectors and may embody a set of input-output coefficients for estimation of intermediate demands. Since the causal relation between the energy sectors and the economy as a whole go in only one direction in the calculation for a particular period, consistent energy-economy interactions are difficult to achieve. The activity of each economic period is built on the period before and affects only the next period. The inter-temporal interactions are simplified.

Instability could be a problem if the equations for several sectors takes the form of difference equations.

A model of this type could be the Hudson and Jorgenson Model for the USA [2].

4.2.5 Economy-wide Optimization Models

Models of this type achieve the goal of embodying the mutual interactions between the energy sector and the rest of the economy. The intermediate demands are usually determined by an input-output matrix with fixed coefficients. The demand for personal consumption by sectors may be determined as shares of total consumption which is being maximized or by their contribution to total utility which is optimized. The models are sectorally and inter-temporally comprehensive and internally consistent. The economy which the models simulates is one with perfect market, so they are normative and the

adjustment of their projections to real conditions requires careful judgment.

A related model of this classification could be the economic-energy model for Chile [3].

4.2.6 General Equilibrium Models

These models have many of the features of optimizing models and also capture the interactions between the energy sectors, energy policies and the rest of the economy. The models contains a number of sectors, including one or more energy sectors. Some are considered static models of a perfect competitive economy for which solutions are calculated. Others incorporate time periods, but the results for each year take all the periods covered by the model into account, so the inter-temporal effects are partially considered. The time structures of these models are recursive and each period builds on the previous period but is not affected by the next period. The production technologies embodied in these models can be linear and/or non-linear, depending on the sectors and the factors of production, so that capital-labor-energy substitutability or complementarity can be reflected. Increasing return to scale relations are directly ruled out in this methodology, as in most others, but some indirect representation can be achieved. Typically, intermediate requirements are determined by an input-output coefficient table and primary inputs are determined by production

functions. Consumption demands for energy and other goods can be determined by specification of consumer utility functions or the demand equations which they imply. Export demands can be specified exogenously or can be made a function of the domestic price which is generated. Imports can be determined either by fixed coefficients or related foreign prices. Investment is either exogenous or determined endogenously by level of savings, and thus, allocates among sectors according to the relative shadow prices on capital stock in each sector. Government taxes and subsidies on goods and resources can be specified explicitly sector by sector. A particular advantage of this type of model is its ability to analyze the implications for price policies of energy sources. In addition, the effects of alternative price interventions on energy and other input-outputs through taxes and subsidies can be analyzed.

The Hudson and Jorgenson Model [2] could be considered as representing this class.

4.3 Relation with the General Equilibrium Model (GEM)

The Hudson and Jorgenson Model is based on a 10 sector Input-Output table with 5 energy sectors (coal, crude petroleum, refined petroleum, electricity and distributed gas) and 5 sectors for the non-energy part of the economy (construction, manufacturing, transportation, services and imports). Given prices for labor and capital, the model simultaneously determines prices for each of the 10 goods

and services and the input-output coefficients for each sector. Given a forecast of labor force and productivity, the model can forecast the levels of demand for each of the 10 goods and services and the amount of capital stock required by each sector. The input-output coefficients for the Hudson-Jorgenson Model respond immediately to a change in the price of energy. In the GEM the input-output coefficients responds gradually to a sudden change in price with the additional feature of the end-use detail for the energy demand.

The ORIM is a mid-term, regionalized, industrial energy demand forecast model. The model forecasts demands for 6 major industrial fuels (distillate fuel oil, residual fuel oil, liquid petroleum gases, natural gas, coal and electricity) and for 9 manufacturing sectors (food, paper, chemical, petroleum, stone, steel, non-ferrous metals, manufacturing and miscellaneous) in the Department of Energy regions for different vintages. The model characterizes each industry as a production function where capital, labor, material and energy are combined to produce the required quantities of industrial output in each forecast year.

The model requires exogenous inputs, projection of industrial production levels, fuel prices, and discount rates for industrial investment. The actual energy demand is calculated in five levels of computation: output, conservation, markets, choices and options.

In the GEM the actual demand is computed in three

levels: options, choices and conservation.

The Economic Energy Model for Chile is a 11-sector input-output table. The first 7 sectors supply various forms of primary or secondary energy (crude oil, crude gas, coal, refined oil, electricity, wood, distributed gas) and 4 other sectors for the nonenergy part of the economy (industry, transportation, services, imports).

A linear programming problem is solved to determine prices for each type of goods. The equilibrium demand of fuels is forecast by the level of options, markets and conservation for each year.

In the GEM, in order to obtain specific information on energy end-use, different features have been added to the disaggregation of sectors, to the structure of the I-O table and to the specification of fuel options.

CHAPTER 5

STRUCTURE OF THE GENERAL EQUILIBRIUM MODEL

A description of the structure and dynamic of the model, the modules organization, the definition of variables and parameters and a characterization of assumptions is what follows in this chapter.

5.1 General Description

The model is organized in four modules: general equilibrium module, energy supply module, energy demand module and final demand module. A simple functional flow diagram of this model is provided in Fig. 5.1, a more detailed equation structure flow diagram in Fig. 5.2 and the modules definitions, codes and structures in section 5.2 and Appendix A.

The core of the model consists of an input-output (I-O) table with a total of $N(i=1,N)$ Goods & Services and $M(j=1,M)$ Processes, in particular $N=16$, $M=20$:

Energy Types; (1) Electricity, (2) Crude oil, (3) Natural gas-well, (4) Natural gas-transported, (5) Natural gas-distributed, (6) Fuel oil-light, (7) Fuel oil-heavy, (8) Liquefied petroleum gas, (9) Coal, (10) Wood.

Types of Goods & Services; (11) Residential, (12) Commercial, (13) Industrial, (14) Transportation.

Types of Factors; (15) Capital, (16) Labor.

Energy Supply Processes; (1) Electricity-hydro, (2) Electricity-nuclear, (3) Electricity-coal, (4) Electricity-oil, (5) Electricity-gas, (6) Electricity-wood/waste/geotherm, (7) Crude oil, (8) Natural gas-well, (9) Natural gas-transported, (10) Natural gas-distributed, (11) Fuel oil-light, (12) Fuel oil-heavy, (13) Liquefied petroleum gas, (14) Coal, (15) Wood.

Energy Demand Processes; (16) Residential, (17) Commercial, (18) Industrial, (19) Transportation, (20) Imports.

Each process is described by an output vector A_{ij} , and an input vector B_{ij} (output/input of good i from/to a unit of operation of process j).

Constraints on level of production Z_j can be imposed exogenously for the levels X_j at which process j is being operated.

The input vectors B_{ij} and the output vectors A_{ij} for the energy supply processes are exogenous constants and the constraints Z_j are exogenous variables. For the energy demand processes the output vectors A_{ij} are exogenous constants while the inputs vectors B_{ij} changes over each period of time.

Given the I-O coefficients for each process, defined from a net output vector $D_{ij}=A_{ij}-B_{ij}$, the composition of final demand $Y_i(t)$ and the prices of labor $P_L(t)$, capital $P_K(t)$ and tax TX_j , the model determine the level of operation for each process X_j and the optimum price $P_i(t)$.

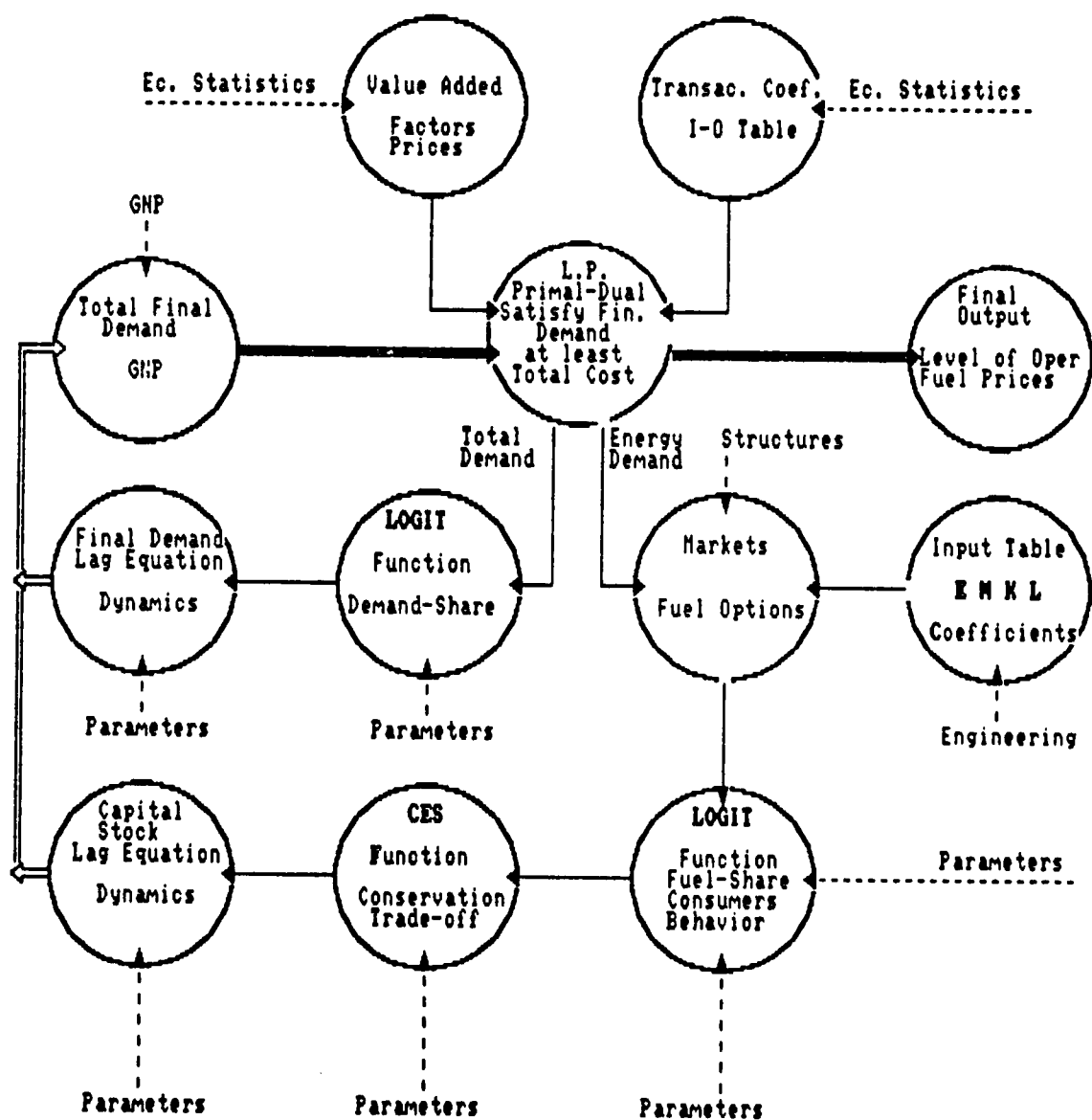


Fig. 5.1 Model Simplified Functional Flow Diagram

The optimality is obtained by solving a linear programming problem (See Appendix D).

Given the optimum prices $P_i(t)$ for the fuels, services and factors, two main elements of the dynamics of the model are calculated:

First, the optimum I-O demand coefficients $B_{ij}^*(t)$ are obtained by essentially three levels of computation: option, choices, and conservation; and second, the optimum final demand shares $YA_i^*(t)$ are determined by a logit demand share function used to simulate the consumer behavior for each energy and service sector.

Fuel options are determined by the type of activity and the corresponding energy coefficient, both to be generated according to an specific end-use design detail.

Choices among options characterize the consumers' behavior in each market or type of activity, and are obtained by a logit fuel-share function.

Conservation or trade-off between type of activities, are represented by a Constant Elasticity of Substitution(CES) function, and the input-output coefficients of unit demand are obtained as minimum cost functions for each type of activity by means of the partial derivative of the CES cost function with respect to prices.

The dynamics itself considers that each period builds on the previous period but is not affected by the next period; a one-way inter-temporal effect. Two lag equations

operates as follow: one equation, in which the actual values for the input demand vector $B_{ij}(t)$ are related to the optimum values $B_{ij}^*(t)$ by a lag parameter μ_j for each process representing the retarded effect of the capital stock investment in each year. The other equation, in which the actual values for the final demand shares $YA_i(t)$ are related to their optimum values $YA_i^*(t)$ by a lag parameter δ representing the retarded effect of the total demand by sector in each year.

Finally, for each of the energy and service sectors the final demand $Y_i(t)$ is the product of the total demand $YT(t)$ and the corresponding shares $YA_i(t)$.

The total final demand, which is the GNP in constant dollars, is exogenous.

The model is solved for each year starting in 1961, the base year is 1977.

5.2 Modules; Variables and Parameters

A comprehensive definition of modules in terms of mathematical notation is given next. In terms of computational notation, a detailed presentation can be found in the computer codes in Appendix A.

5.2.1 The General Equilibrium Module

The General Equilibrium Module uses linear programming to determine the level of operation and the prices; given the I-0 coefficients, the value added, constraints on production

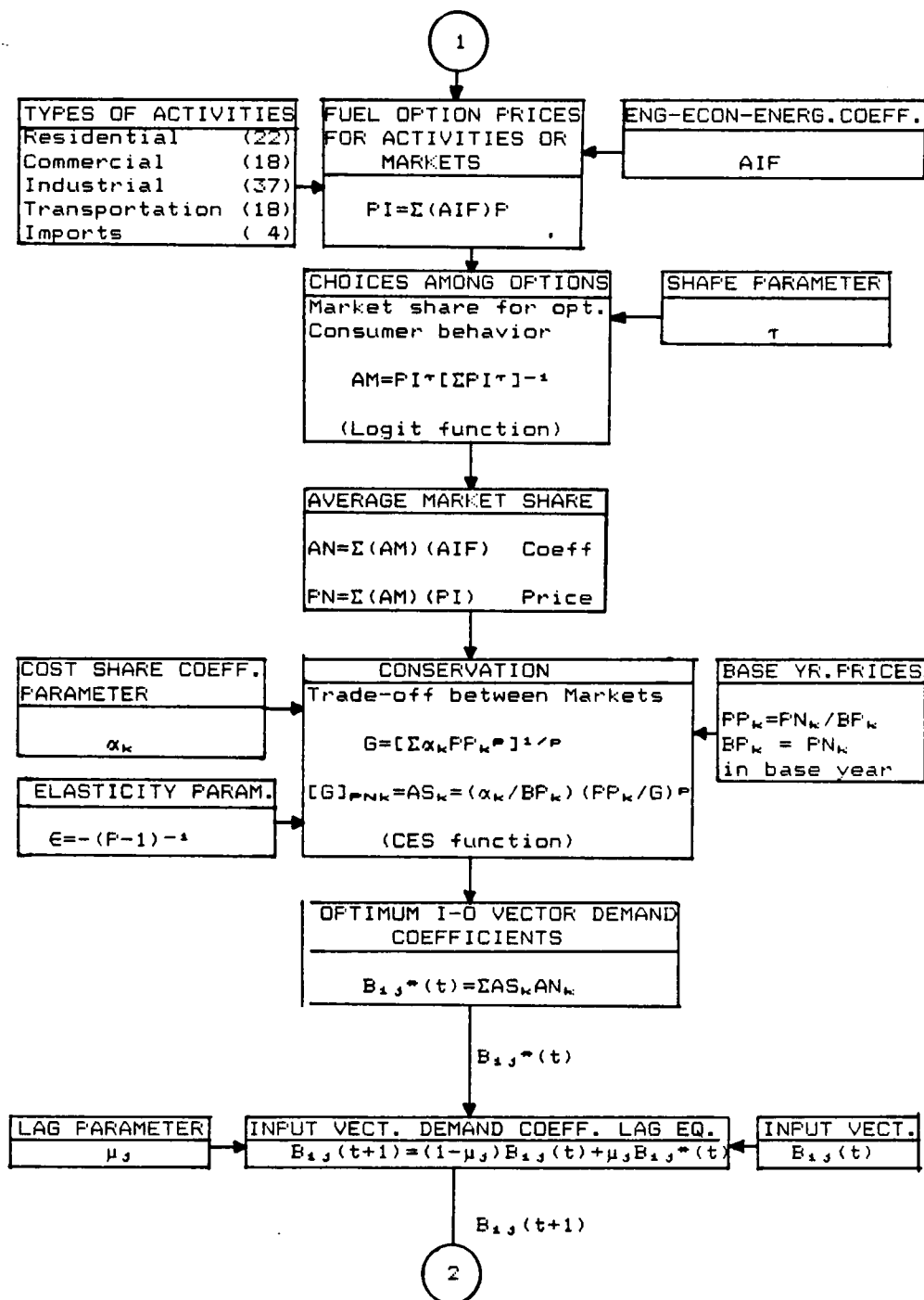


Fig. 5.2 Model Input-Output Equation
Flow Diagram
Second Part

and composition of final demand. The notation is as follows:

N - Sectors (Goods, Services and Factors)

M - Processes (Industries)

A_{ij} - Output vectors of Good, Service or Factor i
from unit of operation of Process j

B_{ij} - Input vectors of Good, Service or Factor i
to a unit of operation of Process j

X_j - Levels of operation (production)

Z_j - Constraints on level of operation

$$0 \leq X_j \leq Z_j$$

V_j - Value Added , $V_j = P_L B_{Lj} + P_K B_{Kj} + TX_j$

P_L - Input Price of Labor

P_K - Input Price of Capital

TX_j - Taxes

Y_i - Final Demands

Linear Programming Problem :

Primal: Minimize $\sum V_j X_j$

subject to $\sum X_j A_{ij} \geq \sum X_j B_{ij} + Y_i$

$$0 \leq X_j \leq Z_j$$

Dual: Maximize $\sum P_i Y_i - \sum \pi_j Z_j$

subject to $\sum P_i A_{ij} \leq V_j + \pi_j + \sum P_i B_{ij}$

P_i - Marginal price (Marginal cost of producing
goods or services).

π_j - Excess profit (Marginal reduction in cost
if constraint j is relaxed).

Summary : Given ; A_{ij} , B_{ij} , V_j , Y_i

Calculate ; X_j , P_i , π_j and

$$\begin{aligned} \text{GNP} &= \sum P_i Y_i \quad \text{Gross National Prod.} \\ &= \sum (V_j + \pi_j) X_j \end{aligned}$$

5.2.2 The Energy Supply Module

For the energy supply module, the I-O coefficients and the constraints are exogenous constants and variables respectively.

A_{ij} , B_{ij} , Z_j - Inputs

5.2.3 The Energy Demand Module

The energy demand module has three levels of computation. Inputs to the module are the AIF coefficients and the prices P_i for goods, services and factors. Outputs are the optimum demand I-O coefficients $B_{ij}^*(t)$. The notation is as follows:

AIF - Input (Engineering-economic-energy coef.)

P_i - Input

$B_{ij}(t+1) = (1-\mu_j)B_{ij}(t) + \mu_j B_{ij}^*(t)$ Lag equation

μ_j - Lag parameter

$B_{ij}^*(t) = \sum A S_k A N_k$ -Output (Optimum I-O demand coef.)

Fuel-Option : Based on a Logit function, gives fuel-option shares .

- AIF = AIF(I,J,K,L) - Input I-O coefficients

(Sectors,Demand Processes,Activity,Fuel-opt.)

$PI_l = \sum AIF P_i$ - Prices for each fuel-option L

$AM = PI^T [\sum PI_l^T]^{-1}$ - Fuel-option share ,(Logit function)

τ - Parameter determining the broadness of the distribution.

Market : Markets are strictly related to the defined activities for each sector.

$PN_k = \sum AM PI_l$ - Avg. cost of energy to each market for each activity K.

$AN_k = \sum AM AIF_l$ - Avg. energy consumption by each market for each activity K.

$AN = AN(I,J,K)$

Conservation : Based on the Constant Elasticity of Substitution function (CES).

$PP_k = PN_k/BP_k$ - Price index

$BP_k = PN_k$ in base year - Base price

$G = [\sum \alpha_k PP_k^p]^{1/p}$ - Output cost function,
(CES function)

$AS_k = [G] PN_k = (\alpha_k/BP_k) (PP_k/G)^{p-1}$ - Output conservation
I-O coef , (Partial derivative of cost function)

p - Substitution parameter

$\epsilon = -(p-1)^{-1}$ - Elasticity parameter

$\alpha = \alpha(J,K,t)$ - Coefficient parameter

5.2.4 The Final Energy Demand Module

The inputs are the prices P_i for goods, services and factors, and the total final demand $YT(t)$. A Logit function gives outputs corresponding to the final optimum demand shares. The notation is as follows:

$Y_i = YT(t) Y_{A_i}(t)$ - Final demand

$YT(t)$ - Total final demand

$Y_{A_i}(t)$ - Final demand shares

$Y_{A_i}(t+1) = (1-\delta)Y_{A_i}(t) + \delta Y_{A_i}^*(t)$ - Lag equation

δ - Lag parameter

$Y_{A_i}^*(t) = \beta_i P_i^v [\sum \beta_k P_k^v]^{-1}$ - Optimum final demand share. (Logit func.).

v - Parameter determining the broadness of the distr.

Summary: Inputs ; $YT(t)$, $P_i(t)$

Outputs; $Y_{A_i}^*(t)$, $Y_{A_i}(t+1)$, $Y_i(t)$

5.3 Basic Assumptions

The two main basic assumptions of the model can be summarized as follows:

First, consider the aggregated "homogeneous" behavior of managers or owners on fuel option decisions regarding engineering systems in facilities, regarding equipment and appliances in houses and buildings, and regarding vehicles in transportation; second, the production-cost function was assumed to be homogeneous of degree one. This implies that at the "factory" level there are no economies of scale, but at

the "industry" level, where there are many factories, the assumption means that there is an optimum size for a factory and expansion occurs by creating new factories. Since the CES cost function applies to the "industry" level, this assumption is not very restrictive.

The word "homogeneous" is used in the sense of defining similar activities of comparable technical, economical and social characteristics. There will be a distribution of fuel prices, at a "factory" level, under the above "homogeneous" conditions (size, number of hours of production, social and environmental standard, existing capital stock, etc.).

If the distributions are broad enough, choosing the least-cost option at the "factory" level may result in all options being chosen at the "industry" level (the processes level of the model).

The simple form of the Weibull fuel shares is the justification for choosing the Weibull distribution instead of a more conventional distribution function.

Both the CES cost function and the Weibull distribution function are approximations of the complex details of industrial production. With a good data base we might find that the CES and Weibull functions are not good enough representations of reality. However, the current data base is really too weak to use and for choosing among various types of production and distribution functions.

The choice has been determined by the simple analytic

formulas which can be derived from the CES and Weibull functions (See sections 3.5, 3.6, and Fig. 5.3, Fig. 5.4).

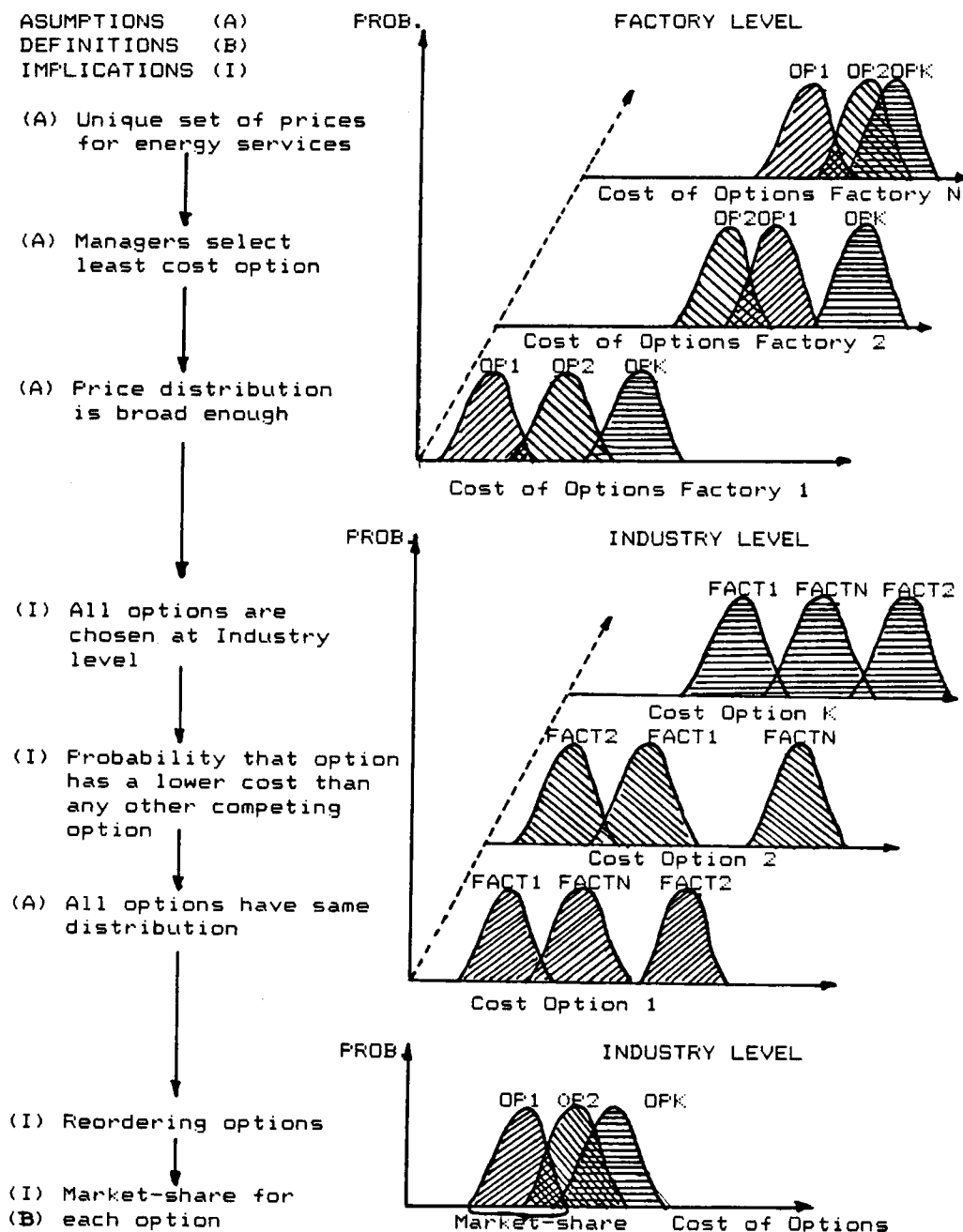
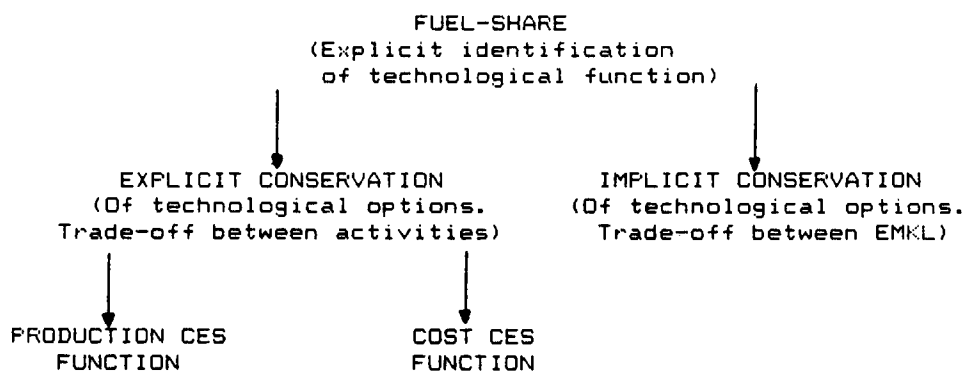


Fig. 5.3 Weibull Market-Share Distribution Function

FUEL-SHARE COST CONSERVATION FUNCTION



$$F = \alpha_0 [\sum \alpha_i X_i^p]^{1/p}$$

$$G = \alpha_0 [\sum \alpha_i P_i^{(e-1)/e}]^{e/(e-1)}$$

where

α_0	: Efficiency parameter
α_i	: Distribution parameter
$E = 1/(1-p)$	: Elasticity parameter
p	: Substitution parameter
X_i	: Production variables
P_i	: Price variables

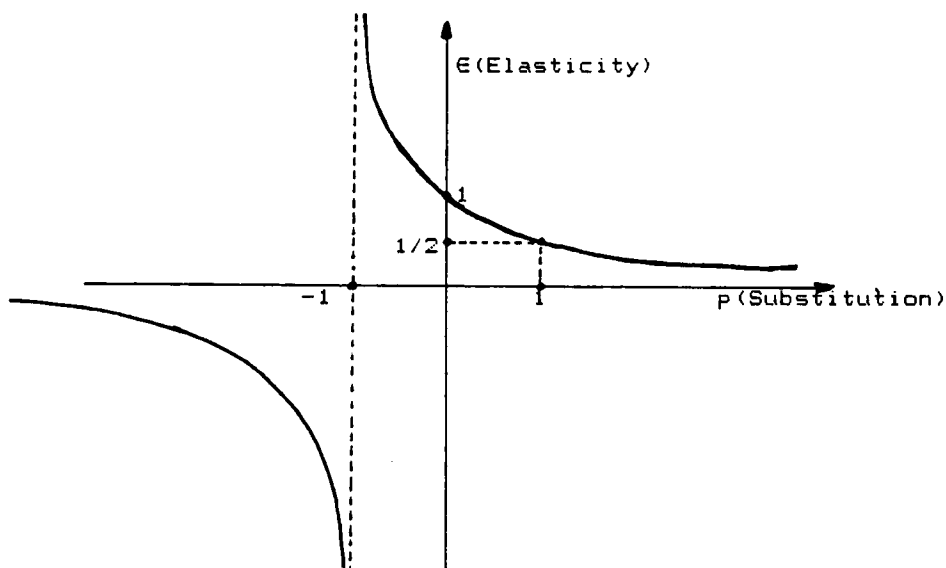


Fig. 5.4 Constant Elasticity of Substitution
Fuel-Share Conservation Function

CHAPTER 6

METHODOLOGY

Several aspects of the methodology have been presented previously in the chapter on the structure of the model, Chapter 5. In this chapter the four main characteristics of the methodology are described in more detail: the input-output table, the engineering-economic-energy coefficients, the parameters and the exogenous variables.

6.1 The Input-Output Table

The input-output tables and coordinated information on labor and capital provide the central data for the model.

In general the input- output table gives a detailed accounting of the amounts of fuels and services that individual industries buy from and sell to each other in a particular year. Reading across each row, we see the amounts of fuels that a particular sector sold to all industries, including itself, and to the "final demand" or final user categories: households, government, foreign trade, net inventory change and gross private capital formation. Transactions are measured in dollars, although they could be measured in physical units (BTU, tons, number of units produced and so on). The bottom rows gives "value added" for each industry, which is the sum of its payments to labor and of its capital

charges, profits, direct taxes or other disbursements.

Input-output coefficients are obtained by dividing the entries in a column, which is an industry's input, by that industry's output. Input-output coefficients enumerate the amounts of goods and services purchased from all other industries and from value added, per unit of its own output. A column of coefficients then gives a detailed quantitative description of the technique of production used by an industry. In general no matter how disaggregated the sectoring, there will be structural changes in "technology" and those due to changes in fuel substitution. The coefficients in any given cell will be a weighted average of sub-coefficients characterizing sub-products. For example, coefficients for electricity into light fuel-oil is an output weighted average coefficient for electricity inputs into motor gasoline, aviation gasoline, jet fuel-oil, kerosene, distillate fuel-oil and group 2 fuel-oil. The coefficients in this cell will change if the electricity requirement per unit of output for any one of these light fuel-oils changes or if the relative importance of, say, motor gasoline increases respect to that of the other fuels.

From the point of view of the system as a whole, however, the distinction is not that clear. Consider the underlying sources of variations in "fuel mix": Changes in the relative importance of different subsectors' outputs result either from changes in the composition of final demand or

from structural changes in other sectors. Motor gasoline decreases in relative importance because the transportation sector is substituting gas and electricity for motor gasoline in a new automobile technology. However, it is not correct to claim that input-output structures depend only on technology or that they include all technological changes.

On the other side, the most detailed industrial and energy statistics for specific relations between technology and economic production functions give an incomplete description of the production process and the technology underlying it.

In compiling the input-output table for the sectors and processes of the GEM, the recent publication of the detailed 537 industry input-output structure of the U.S. economy for 1977 [53] has been used as the primary base for calculation together with the Energy Information Administration (EIA) data.

The methodology in doing this can be organized in five main steps: aggregated energy reading, arrangements and adjustments, EIA data for energy sectors, sectors and processes breakdown and final new I-O table.

6.1.1 Aggregation of Energy

A computer program was written to read the I-O table for the selected 16 sectors and 20 processes of the model, from the computer magnetic tape entitle 537-Industry [54].

Validation of the computer program was made by hand, checking some of the quantities from the detailed input-output structure of the U.S. economy, 537-Industry, published for the year 1977 [53].

A clear visualization of the consumption of goods (USE) and the production of goods (MAKE) by sectors and processes was obtained by arranging in a single table both sets of quantities, having in mind that the USE represents the B_{ij} input vectors and the MAKE represents the A_{ij} output vectors as described in Chapter 5.

The identification of the I-O table classification with the model's sectors and processes is as follows:

A specific code number of the I-O table defined for a particular industry was allocated to a selected sector of the model. For example, in the energy supply, electricity consumed and produced by the private electric utilities (code 68.0100), the federal electric utilities (code 78.0200) and the state electric utilities (code 79.0200) were aggregated as electricity consumed or produced by the electric sector, which in turn was disaggregated in further calculations as six different types of electric processes. In the energy demand, all industries defined by the codes 1.0100 to 64.1200 were aggregated as the industrial sector excluding those with energy contribution as defined by codes 7.0000, 8.0000, and 31.0101, with the result provided in the following classification:

I-O CLASSIFICATION	CODE NUMBER	MODEL'S SECTOR & PROCESSES
Coal mining	7.0000	C
Crude petroleum and Nat.gas	8.0000	CO, NG/W
Petroleum refining	31.0101	FO/L, FO/H, LPG
Electric service	68.0100	E/H, E/N, >
Federal electricity	78.0200	E/C, E/O, >
State electricity	79.0200	E/G, E/W >
Gas Product. and Distrib.	68.0200	NG/T, NG/D
Local Gov. passenger trans.	79.0100	Transportation
Owner-occupied dwelling	71.0000	Residential
65.0000 < code numbers ≤ 85.0000		Commercial
1.0100 ≤ code numbers ≤ 64.1200		Industrial
64.1200 < code numbers ≤ 65.0800		Transportation
Compensation to employees	88.0000	Labor
Indirect business taxes	89.0000	Capital
Prop. Income, Int., Cap.	90.0000	Capital
Exports	94.0000	Exports
Imports	95.0000	Imports
85.0000 < Final Demand ≤ 99.9000		Close economy

6.1.2 Arrangements and Adjustments

Arrangements and re-ordering were made, as needed, in the aggregation of the electric, transportation, and capital sectors, as well as in the corresponding processes.

Minor adjustments were needed in order to achieve

balance for every sector and process, and to match the value added with final demand.

The energy part of final demand was allocated to the residential and transportation processes keeping control total in balance (see Appendix L, Table A).

In Table A a particular column represents a given industry, and that industry consumes (USE) and produces (MAKE) quantities (10^6 US\$) of fuels. For example, the electric industry consumes electricity, natural gas, refined petroleum and coal; uses commercial, industrial and transportation services; and uses capital and labor. Money going into the industry balances money going out. On the other side, a particular row represents a given fuel, service or factor consumed or produced by the different industries. For example, electricity is being consumed by different industries and is produced mainly by the electric industry, except for a small quantity generated by the commercial sector and some imported from Canada. Total consumption of electricity equals total production.

There are no transactions of electricity representing the consumption within the electric industry. This type of information is captured in the new I-O table.

6.1.3 Energy Information Administration Energy Data

The energy supply and demand data obtained from EIA publications are not always consistent one to the other.

Depending on the sector, a supply or demand approach has been taken. Each sector has its own characteristics, and the methodology used to obtain the USE and the MAKE of energy for each sector follows a pattern with specific individual details.

A scheme for this pattern is as follows:

a) Calculate the average price of each fuel in the sector by subtracting the self consumption of the main industry producing such fuel, given by the I-O table, from the total commodity output for the sector in units of [\$], and divide by the total energy consumed by the sector, given by EIA data, in units of [BTU].

b) Aggregate or disaggregate the energy demand or supply data in terms of the selected fuels for the sector, maintaining a single common unit (10^{12} [BTU]). Match the total energy consumption and production for each fuel.

c) Apply the average price for each fuel to the above consumption or production entries and match the total in the I-O table figures (10^6 [\$]) for the fuel and for all fuels in the sector.

An example calculation for the Petroleum Refining sector together with data references used for the other sectors is presented in Appendix E.

The entries in the energy block of the new I-O table will not necessarily coincide with the original I-O table because there are several transactions on the original table

that do not represent fuel trades for consumption or production. These differences need to be accumulated somewhere in the table, and the logical sector to absorb these differences (positive or negative) is the commercial sector.

So essentially, for the non-energy block of the table, we preserve the input-output figures from the original table corresponding to the residential, industrial, transportation, capital and labor sectors and modify the corresponding entries of the commercial according to the differences. The result will be that we are preserving the sum of the columns; in other words, we are reaching the same balance for each process as in the original table.

6.1.4 Breakdown of Sectors and Processes

Within the energy block, we split each sector into its fuels components according to calculated energy quantities or proportion as is shown in the Petroleum Refining example.

ELECTRICITY	=>	E/H, E/N, E/C, E/O, E/G, E/W
CP. & N. GAS	=>	CO, NG/W
GAS P. & D.	=>	NG/T, NG/D
PETR. REF.	=>	FO/L, FO/H, LPG
COAL	=>	C
WOOD	=>	W

For the non-energy block, we split each process into its

selected industries in proportion to their respective production obtained from the dollar quantities within the new I-O table.

6.1.5 Final-New Input-Output Table

Finally, if there is a negative quantity for the commercial sector it can be turned positive by transferring the appropriated quantity from the USE to the MAKE or viceversa for each industry, with the implication that a new I-O balance will be attained for those industries and for the commercial sector as a total (see Appendix L, Table B).

In Table B a particular column, say the import industry consume (USE=EXPORT) and produce (MAKE=IMPORT) quantities (10^6 US\$) of fuels and services. The foreign trade is in balance. There is no single row corresponding to the import because it is included in all the fuel and service sectors.

6.2 The Engineering-Economic-Energy Coefficients

The demand for each type of energy service within a particular process is allocated to markets which are differentiated by characteristics such as region, size, capacity and efficiency of the equipment or device, social-economical-environmental standards, operation and maintenance, capital stock and fuel options.

The above markets define activities such that for each process demand we obtain the following general configuration:

PROCESS DEMAND	NUMBER OF ACTIVITIES		TOTAL	FIGURE N ^o
	FUEL	SERVICE & FACTOR		
RESIDENTIAL	18	6	22	6.2
COMMERCIAL	12	6	18	6.3
INDUSTRIAL	31	6	37	6.4
TRANSPORTATION	12	6	18	6.5
IMPORTS		4	4	

In each market or activity, options exist which use one or more of the ten types of fuels to produce the appropriate energy services for each process demand. An idealized machine could serve to illustrate for each process demand the consumption of different types of fuels to generate the required energy services. More on this is presented in the Industrial Process.

The figures 6.2, 6.3, 6.4 and 6.5, represent the residential, commercial, industrial and transportation sectors respectively, partitioned in the way the model considers the different fuel options to interact in the functional use within the various structures or modes and regions. The quantities correspond to the shares of 1[BTU] consumed at each level in the year 1977.

Next, there is a summary description for each process demand.

6.2.1 Residential.

A single-family unit located in the south of the USA, essentially needs four types of energy services: space heat, water heat, air conditioning and others (services to cook, to cool food, to illuminate, etc.).

A typical house of 1625 [sf] uses 32.4×10^6 [BTU/YR] to heat space, 12.4 to heat water, 32.4 to condition the air and 36.5 for others of the same unit [75], [76], [77].

Energy services could be provided by several fuels and by means of different equipment with its own technology and efficiency.

In this model the bundle characterization is as follows:

<u>SPACE HEAT</u>	ACTIVITY	FUEL OPTION
	13	(Supply sector)
Electric resistance		1
Electric heat pump		1
Low efficiency nat. gas furnace		5
High efficiency nat. gas furnace		5
Low efficiency LPG furnace		8
High efficiency LPG furnace		8
Fuel oil furnace		6
Coal furnace		9
Wood stove with electric back-up		10

	ACTIVITY	FUEL OPTION
<u>WATER HEAT</u>	14	(Supply sector)
Electric resistance		1
Electric heat pump		1
Low efficiency nat. gas furnace		5
High efficiency nat. gas furnace		5
Low efficiency LPG furnace		8
High efficiency LPG furnace		8
<u>AIR CONDITION</u>	15	
Electric central unit		1
Electric window unit		1
<u>OTHERS</u>	16	
Refrigeration		1
Cooking		1,5,8
Dish washing		1
Clothes washing		1
Clothes drying		1,1-5,1-8*
Lighting and rest		1

* 1-5,1-8 are complementary fuels

The means of providing the required energy service for each activity is represented by cost input coefficients accounting for the costs of energy, material (commercial, industrial, transportation), capital and labor.

We call these coefficients, engineering-economic-energy coefficients and their calculation is performed as follows:

Define:

The required energy year demand for each energy service.

A basic unit of energy demand, say 10^6 [BTU].

The efficiency for each type of equipment.

The capital cost and annual O&M costs

Compute:

The Energy coefficients.

The Material, Capital and Labor cost coefficients.

The levelized annual capital charge rate ϕ , Appendix F.

Obtain: The AIF(M,N,NN,NI) coefficients for:

M = Fuel (Sector supply), N = Residential process

NN= Activity 13,14,15,16, NI= Corresponding fuel-option

Tables carrying out the calculation for a single-family unit in the south are presented in Appendix G.

The basic assumptions used to calculate the input AIF coefficients, for the north and for multi-family units north and south, are stated in the following arrangement:

STUDIES	BASIC DATA	APPLICABLE	DIRECT	ENERGY & PRICE
.	FOR	TO	EXTENSION	WEIGHT EXTENS.
Gas Research	Space heat	Sgl-fam u.	Sgl-fam u.	
<u>Ins. [75]</u>	Water heat	<u>Chicago</u>	<u>North</u>	Sgl&Mul-fam u.
TVA[76],[77]	Air cond.	Sgl-fam u.	Sgl-fam u.	North & South
.		TVA region	South	.
TVA[76],[77]	Others	All living	Sgl&Mul u.	Sgl&Mul-fam u.
.		u. TVA reg.	South	North & South

Assumptions of the right are implied by studies from left.

From the tree diagram, Fig. 6.2, for 1[BTU] consumed we have made the following assumptions:

	Sgl-fam	Mul-fam	Factor to adjust EKLM coeff. for an equivalent energy service in Mul-fam	
			E	KLM
NORTH	0.66	0.34	$(0.34/0.66)=0.51$	$(0.51)^{-1}=1.96$
SOUTH	0.59	0.41	$(0.41/0.59)=0.69$	$(0.69)^{-1}=1.45$

These weight extension factors apply to space heat, water heat and air conditioning. The requirement of energy services for "others" are considered the same in Sgl-fam and in Mul-fam.

The residential structure is presented in Fig. 6.2. The ten U.S. Federal Regions were aggregated as in Fig. 6.1.

An additional assumption to break down Material into Commercial, Industrial and Transportation was used for the Residential and Commercial Processes as follows:

SECTOR	FUEL	COMM.	IND.	TRANSP.
1	E	.4	.5	.1
5	NG/D	.6	.3	.1
6	FO/L	.8	.1	.1
8	LPG	.4	.5	.1
9	C	.6	.3	.1
10	W	.6	.3	.1

A complete table with the AIF coefficients is included in Appendix B.

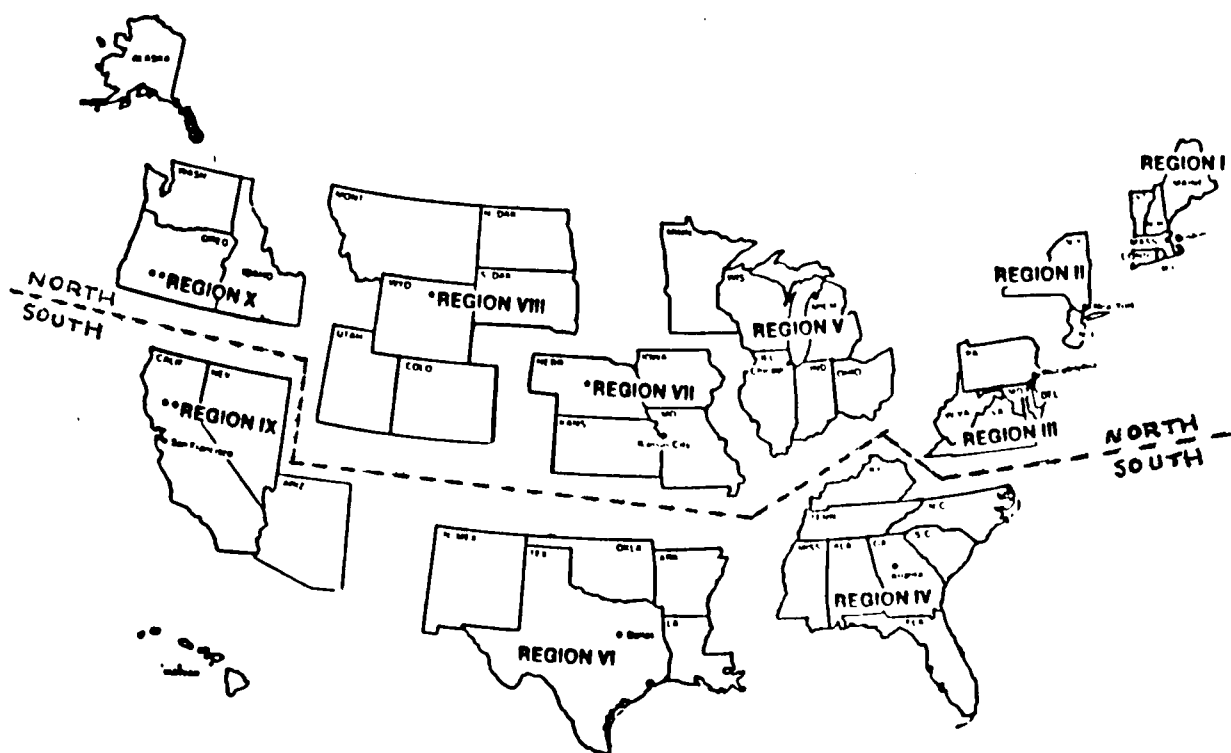


Fig. 6.1 Federal Energy Regions in the U.S.

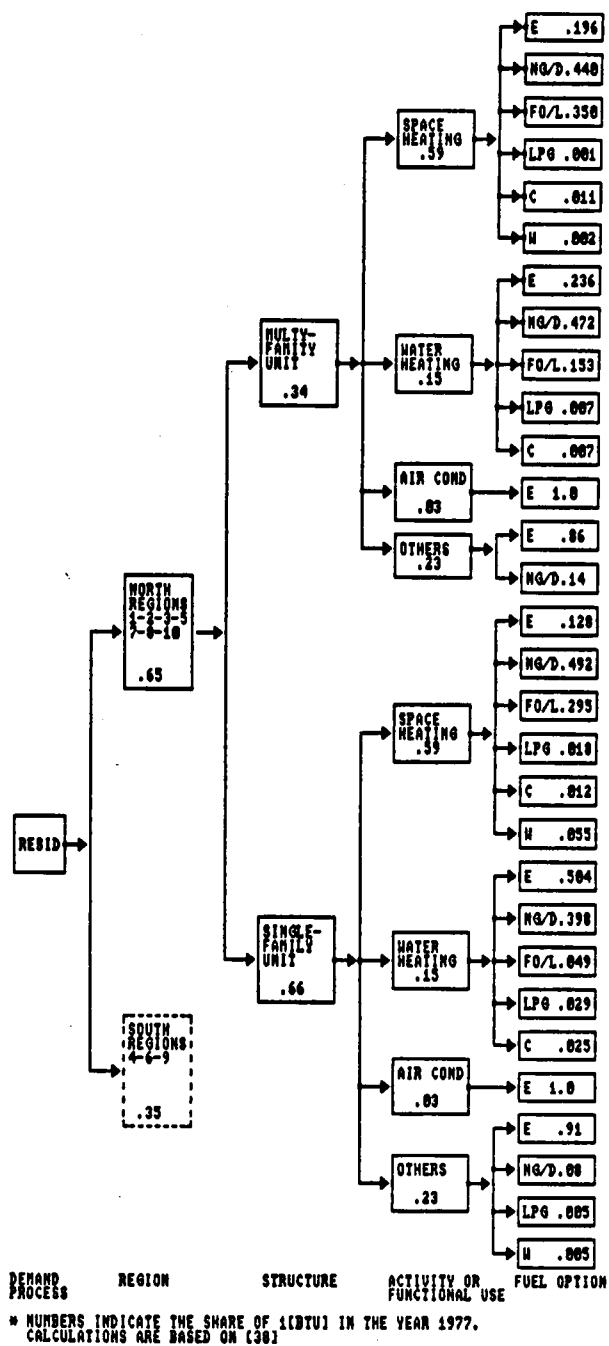


Fig. 6.2 Residential Energy Consumption
Tree Diagram.
First Part

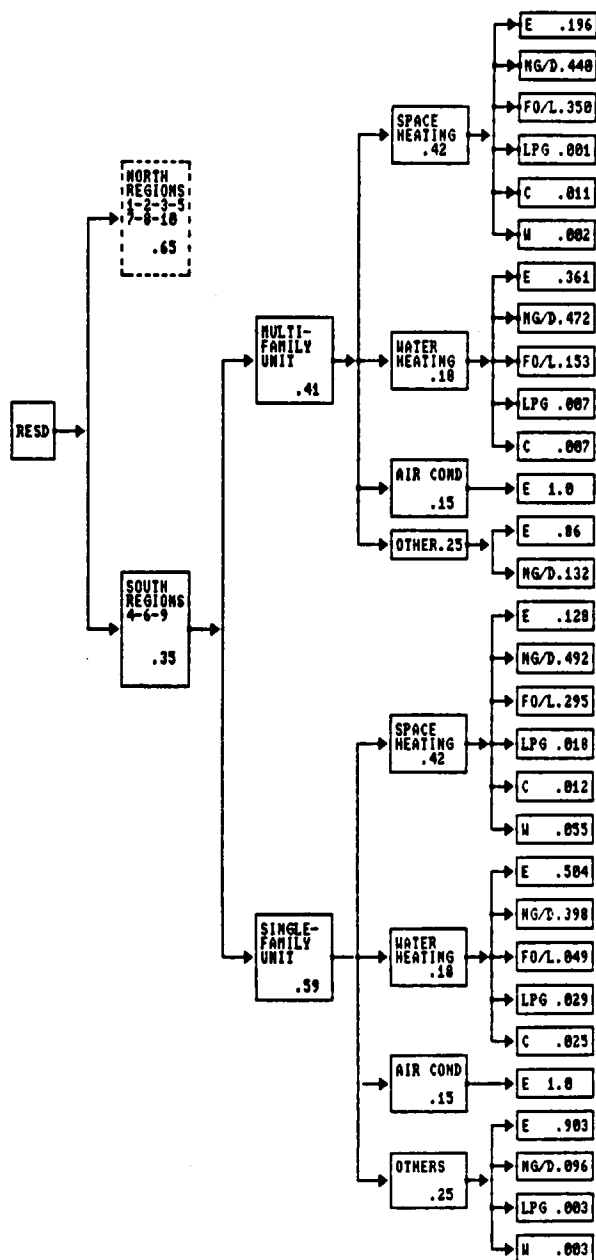


Fig. 6.2 Residential Energy Consumption
Tree Diagram
Second Part

6.2.2 Commercial.

This process demand is described without distinction between north and south; this is not very restrictive because of the building structures and insulation.

By studying the data obtained from [36] and [37], it appears reasonable to aggregate the buildings in a way that energy consumption approach homogeneous consistency with respect to the required energy services.

Under this consideration, the aggregated structure given in Fig. 6.3 and the activities selected for each energy service were chosen as the basic configuration to derive the required data assuming the following considerations:

BASIC DATA FROM	AVERAGE DATA	DIRECT EXTENSION	EMKL WEIGHT
<u>RESID. PROCESS</u>	<u>APPLICABLE TO</u>	<u>FOR</u>	<u>EXTENS. FOR</u>
<u>Mul-fam u.north</u>	Mul-fam u.N&S	Aggreg. A	<u>Aggreg. B</u>
<u>Mul-fam u.south</u>			<u>Aggreg. C</u>

Assumptions of the right are implied from the left and the aggregation corresponds to:

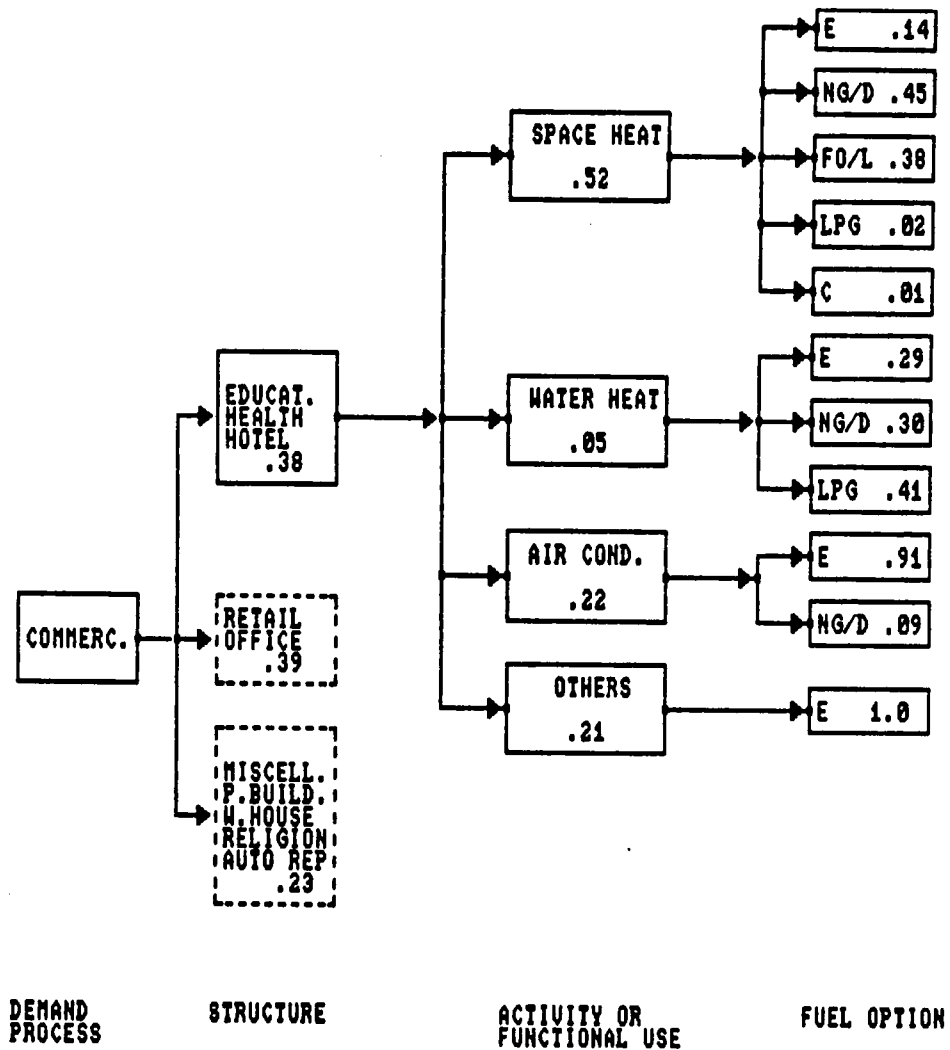
- A Educational-Health-Hotel
- B Retail-Office
- C Miscell.-Pub.building-W.house-Religion building-Aut.Rep.

The weighted extension going from A to B and to C considers factors 1.0, 1.05, 1.1, 1.0 and 1.0, 0.95, 0.9, 0.9 to apply for energy, material, capital, labor respectively.

The bundle characterization is as follows:

	ACTIVITY			FUEL OPTION
	A	B	C	(Supply sector)
<u>SPACE HEAT</u>	1	5	9	
Electric resistance				1
Natural gas furnace				5
Fuel oil furnace				6
LPG furnace				8
Coal furnace				9
<u>WATER HEAT</u>	2	6	10	
Electric resistance				1
Natural gas furnace				5
Fuel oil furnace				6
<u>AIR CONDITIONING</u>	3	7	11	
Electric A.C.				1
Nat. gas A.C.				5
<u>OTHERS</u>	4	8	12	
Elevator				1
Refrigerator				1
Cooking				1
Dish washing				1
Clothes washing				1
Clothes drying				1
Lighting and rest				1

A complete table with the AIF coefficients is included in Appendix B.



* NUMBERS INDICATE SHARES OF 1(BTU) IN THE YEAR 1977.
CALCULATION ARE BASED IN [37].

Fig. 6.3 Commercial Energy Consumption
Tree Diagram
First Part

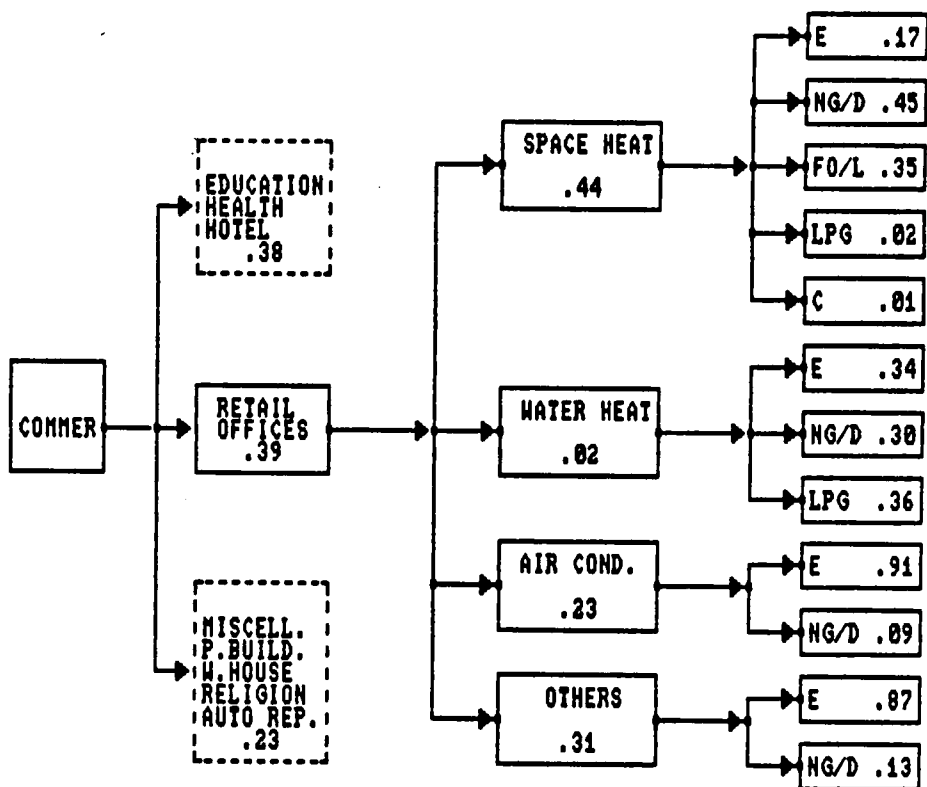


Fig. 6.3 Commercial Energy Consumption
Tree Diagram
Second Part

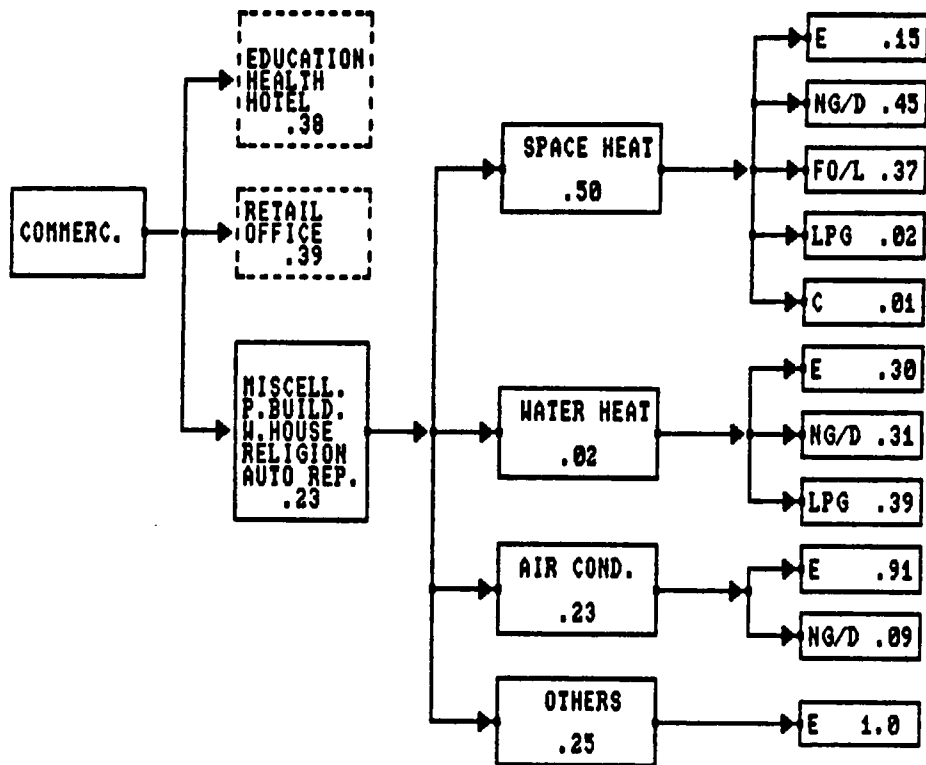


Fig. 6.3 Commercial Energy Consumption
Tree Diagram
Third Part

We tried to introduce the new fluidized coal bed combustion (FCBC) technology competing against the traditional stoker-fired boiler, based on a study conducted by the University of Tennessee, College of Engineering, in 1980 [80]. The general structure of aggregation A did not allow consistency of data.

6.2.3 Industrial.

The structure of this process was obtained by aggregating the different industries, considered in [1], in four groups as described in Fig. 6.4:

- A Agriculture-Construction-Mining
- B Food-Paper-Chemicals
- C Stone-Primary Metals
- D Manufacturing-Miscellaneous

Groups B,C,D are manufacturing industries, group A can be assimilated as industry if we take appropriate considerations to the energy end use.

For the Industrial process, energy service can be defined by the amount of fuel input to an idealized machine which produces each of the energy services. There are four energy services provided by this ideal machine: process steam, process heat, machine drive and electrical service. These services are being produced by fuels such as electricity, natural gas, light fuel oil, heavy fuel oil, liquefied petroleum gas, coal and wood.

Since in the real world there are several machines with different technologies and characteristics that produce one particular energy service, we need to define a reference machine for the generation of each energy service and to calculate the engineering-economic-energy coefficients for Energy, Material, Capital and Labor relative to that particular reference machine.

In Reference, [1] Vol.II and III, there is a complete description of the methodology used to generate these AIF coefficients.

Aggregation of data and adaptation of functional relations have been made to generate the coefficients needed for this model.

```

E      ==>
CO      ==>          REFERENCE SYSTEM
NG/W    ==>  =====
NG/T    ==>  Large nat. gas boiler, eff= .88 ==> PROC. STEAM
NG/D    ==>  Large nat. gas unit, eff= .65   ==> PROC. HEAT
FO/L    ==>  Large nat. gas turbine, eff=.30 ==> MECH. DRIVE
FO/H    ==>  Large unit, eff= .90           ==> ELEC. SERVICE
LPG     ==>  =====
C       ==>          IDEAL MACHINE
W      - ==>

```

The bundle characterization for A is as follows:

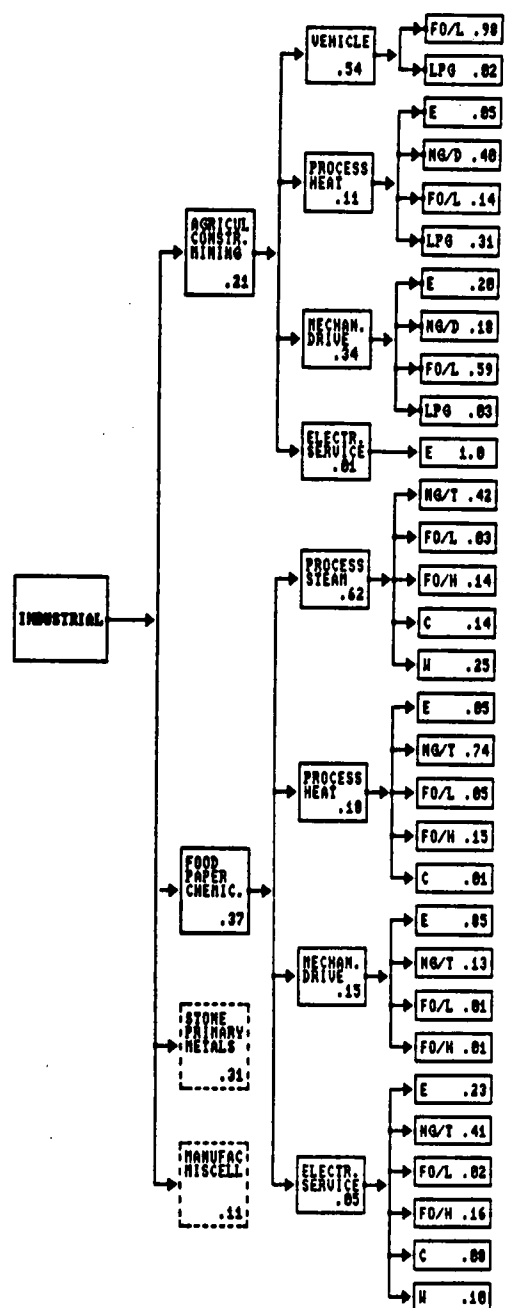
	ACTIVITY	FUEL OPTION
	A	(Supply sector)
<u>VEHICLE</u>	1	
Fuel oil vehicle (Heavy duty)		6
LPG vehicle		8
<u>PROCESS HEAT</u>	2	
Electric resistance		1
Nat. gas furnace		4
Fuel oil furnace		6
LPG furnace		8
<u>MECHANICAL DRIVE</u>	3	
Electric motor		1
Nat. gas turbine		4
Fuel oil turbine		6
LPG turbine		8
<u>ELECTRIC SERVICE</u>	4	
Electric service		1

To generate the corresponding data, the following basic assumptions were made:

TO OBTAIN EMKL COEFF. FOR:	TAKE AVERAGE DATA FROM:	
	DEMAND PROCESS	ACTIVITY
VEHICLE	Transportation	4
PROCESS HEAT	Industrial B,C,D	10,19,28
MECHANICAL DRIVE	Industrial B,C,D	12,21,30
ELECTRIC SERVICE	Industrial B,C,D	13,22,31

The bundle characterization for B, C, D is as follows:

	ACTIVITY			FUEL OPTION
	B	C	D (Supply sector)	
<u>PROCESS STEAM</u>				
Large, high capacity factor, coal				
feasibility, no co-generation boiler	5	14	23	4,6,7,8,9
Small, low capacity factor, coal				
feasibility, no co-generation boiler	6	15	24	4,6,7,8,9
<u>PROCESS HEAT</u>				
Large, high capacity factor, coal				
feasibility, no co-generation furnace	7	16	25	4,6,7,8,9
Large, high cap. fact., no coal feas.,				
(clean process), no co-gener. unit	8	17	26	1,4,6,8
Small, low capacity, coal feasibility,				
no co-generation furnace	9	18	27	4,6,7,8,9
Small, low cap. fact., no coal feas.,				
(clean process), no co-gener. unit	10	19	28	1,4,6,8
<u>MECHANICAL DRIVE</u>				
Large, high capacity factor,				
direct heat, boiler	11	20	29	1,4,6,7,8
Small, low cap. fact, direct heat,				
no heavy fuel oil (clean), boiler	12	21	30	1,4,6,8
<u>ELECTRIC SERVICE</u>				
Electric service (light, electrolysis)	13	22	31	1



DEMAND PROCES STRUCTURE ACTIVITY FUEL OPTION
 * NUMBERS INDICATE THE SHARE OF LBTU IN THE YEAR 1977
 CALCULATIONS ARE BASED ON 1971, 1973

Fig. 6.4 Industrial Energy Consumption
 Tree Diagram
 First Part

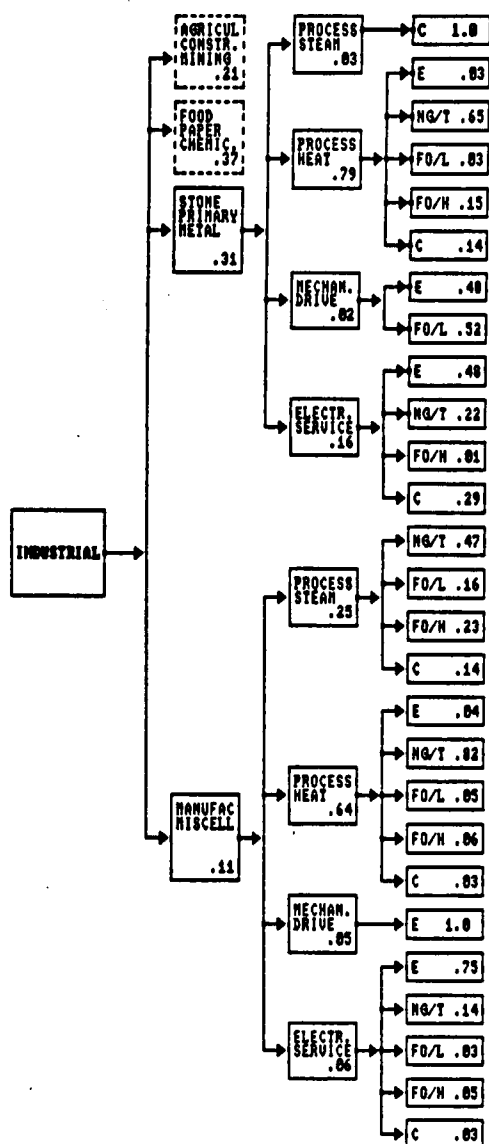


Fig. 6.4 Industrial Energy Consumption
Tree Diagram
Second Part

To break down the Material coefficients into Commercial, Industrial and Transportation, the following assumptions were made:

SECTOR	FUEL	COMM.	IND.	TRANSP.
1	E	0.4	0.5	0.1
4	NG-T	0.6	0.3	0.1
6	FO-L	0.8	0.1	0.1
7	FO-H	0.6	0.3	0.1
8	LPG	0.4	0.5	0.1
9	C	0.6	0.3	0.1
10	W	0.6	0.3	0.1

A complete table with the AIF coefficients is included in Appendix B.

6.2.4 Transportation.

In the transportation process demand there are only a few possibilities for fuel options within a single activity. Vehicles are technologically designed to run on a single fuel, at least with respect to the fuels considered in this model.

There are some experimental vehicles being tested for markets in the near future, such as the electric car for short distances and the compressed natural gas fueled school bus. The first experimental testing is a national program with the objective to introduce in specific markets an electric van by 1990, as a fleet concept. The second one is a

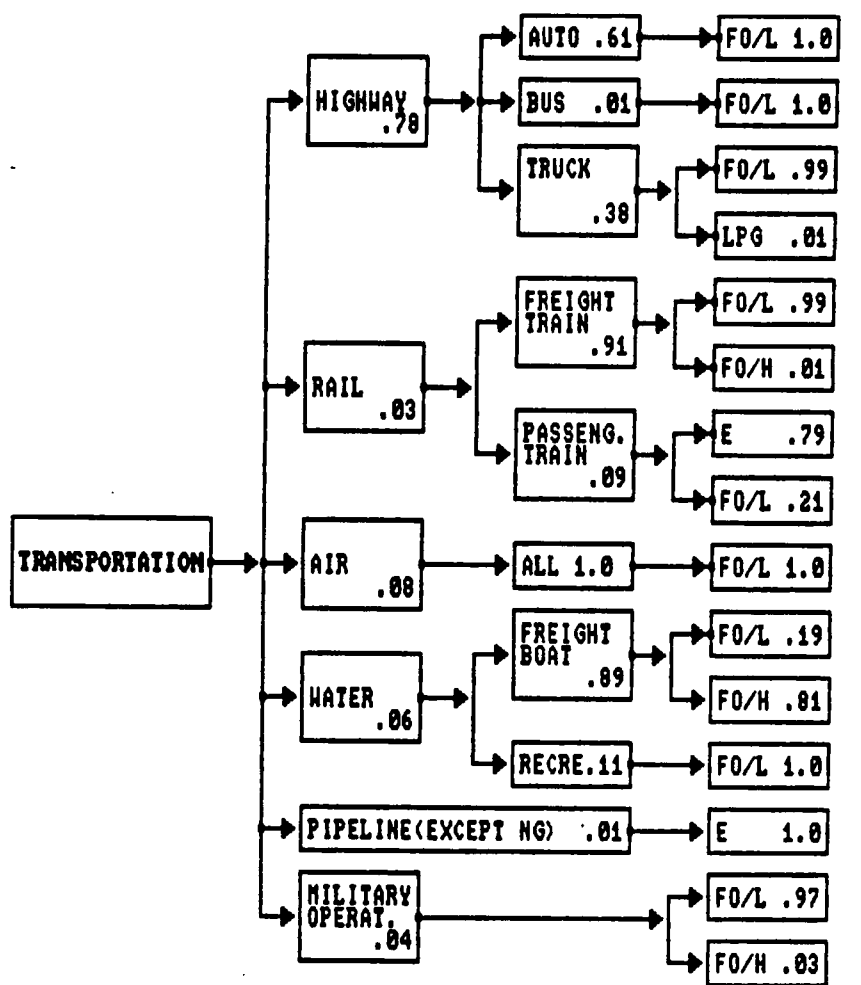
local program also being conducted in other parts of the U.S.

In both cases the data gathered from the prime developers (TVA, Chattanooga and Oak Ridge Tennessee, School Board) is being considered in the model. Reference [78]a,[78]b,[44].

The structure of the transportation process for this model, as can be seen in Fig. 6.5, considers five modes of transportation and military operations, 12 activities and the corresponding fuel options.

The bundle characterization is as follows:

	ACTIVITY	FUEL OPTION
<u>HIGHWAY</u>		(Supply sector)
Standard car	1	6
Compact car	1	6
Sub-compact car	1	6
Short distance (100mi) electric Van	2	1
Short distance Van	2	6
Bus-intercity	3	6
Bus-transit compress nat. gas (School)	4	5
Bus-transit	4	6
Truck	5	6
<u>RAIL</u>		
Passengers, train and transit	6	1
Freight trains	7	6
<u>AIR</u>		
General and carrier airplanes	8	6



DEMAND PROCESS

STRUCTURE OR
MODEACTIVITY OR
FUNCTIONAL USE

FUEL OPTION

* NUMBERS INDICATE THE SHARE OF 1[BTU] IN THE YEAR 1977
CALCULATIONS ARE BASED ON [74]

Fig. 6.5 Transportation Energy Consumption
Tree Diagram

<u>WATER</u>	ACTIVITY	FUEL OPTION
Recreational	9	6
Freight	10	7
<u>PIPELINE</u>		
Transportation of:CO,Pet.products, coal slurry, water(NG not included)	11	1
<u>MILITARY OPERATION</u>		
Land, water and air transportation	12	6

A table with the AIF coefficients is in Appendix B.

6.2.5 References for the calculation of AIF coefficients.

RESIDENTIAL : [33],[34],[35],[38],[38 Appendix A,B]
 [38 Computer print-out]
 [75],[76],[77]
 [93]
 [43]

COMMERCIAL : [36],[37],[37 Computer print-out]
 [93]
 [42]

INDUSTRIAL : [1] Vol 1, Vol 2
 [72],[73]

TRANSPORTATION : [61]
 [74],[79],[78a],[78b]
 [47]

Some of the assumptions made on data are based on personal communications.

6.3 Parameters of the model

Gathering a full set of data parameters is important in order to obtain the calibration or alignment and the validation of the model. On the other side, the compilation of a full set of data parameters for all years in consideration is a very difficult task and a very long process. Some compromises have been taken in averaging, assimilating and approximating parameter data.

The parameters used in the model are:

- Exponent of the fuel-share function (Logit function) for each Demand process, (Shape parameter):
 τ or RN(Demand procecess)
- Exponent of the conservation function (CES function) for each Demand process, (Control price elasticity parameter):
 ϵ or RT(Demand processes)
- Exponent of sectors final demand-share function (Logit function): v or RY
- Lag parameter for total final demand in Lag equation:
 δ or CY
- Lag parameter for demand input vectors in Lag equation:
 μ or CA(Processes)
- Cost share coefficients for the CES function for each activity within each Demand process :

α or DD(Demand processes, Activity, Year)

1961(First year)	1974(Oil crisis year)
1977(Base year)	1985(Last year)

- Coefficient for the Logit final demand-share function for each Demand process for years 1961,1974,1977,1985:

β or DF(Demand processes,Year)

The complete data parameter set is included in Appendix B.

5.4 Other Exogenous Variables.

The following exogenous variables allow the model to produce information for the analysis of different economic-energy policies:

- Fuel prices in the base year: BPFU(Fuel sectors)
- Total energy demand by energy supply sectors and total demand by energy demand sectors on base year: YA(Sectors)
- Price of capital in years 1961,74,77,85 : PK(Year)
- Price of labor " " " : PL(Year)
- Taxes by processes " " : TX(Proc.,Year)
- Gross National Product in each year : YT(Year)
- Limits on energy production : ZJ(Proc.,Year)

The complete data set is included in Appendix B.

CHAPTER 7

CALIBRATION AND VALIDATION

A policymaker who uses model output to help decision making process wants to know how good the forecast is likely to be. An analyst or researcher who wants to improve the results of a model need information on the origin and extent of the possible errors.

7.1 Overview

Virtually every step of the forecasting process includes some errors.

Errors occur in the specification of the model; some complex models include variables that affect the values of forecast variables in the real world, so errors are inevitable, on the other side, some relatively simple models may omit very important variables.

There is also error involved in the functional form used in specifying a structural equation.

In many models, there are forms of errors associated with data used to estimate parameters; often there are few observations, reducing the credibility of the estimated parameter.

--For most data, and this is the case here, trends occurring over time are not the same as cross-sectional variations

which by definition occur at a single point in time.

There are errors associated with data collection, coding errors, transcription errors and many others.

One of the most important sources of errors in forecasting comes from the projection of the value of the independent variables into the future. The error these variables carry with them into the forecast period amplifies the error already embodied in the structure, parameter estimates, and functional form of the forecasting system.

In a sense the validation of a model could be very simple if all type of errors were reduced as much as "reasonably possible", or it could be almost impossible to accept validation if the errors were difficult to avoid.

There are several methods for validating a model.

Some models use all consistent available data up to the beginning of the forecast period to estimate parameters to gain great accuracy. For such models a simple, but effective, validation based on an appropriate percentage of reproducing the historical data would be sufficient.

The GEM uses EIA data from 1961 to 1985, in order to evaluate the coefficients and validate the form of the model. Validation of the model is defined as matching, to a certain percentage, the historical data for that period. The errors between model results and data are presented for each of the fuels sectors.

7.2 Calibration

A necessary first step was to have the computer codes running after the process of debugging.

A second step was to obtain an external sub-routine ZX4LP, from the ISML library, working as it was expected. At this level the sub-routine described in Appendix C, which solves the linear programming problem via the revised simplex algorithm, was giving no output because of overflows and underflows.

To locate the problem, the data for the base year 1977 were organized as an input for the well-known linear programming software MPSX. The results given by these codes show that the data were consistent and eliminates these elements as sources of error. Further investigation revealed that the inconsistency was on the dimensionality of some arrays used by the sub-routine.

The process of obtaining outputs for all 25 years was performed in parallel with adjustments and corrections of the input data when errors were detected.

The first goal in the process was to get some numbers. Once we obtained acceptable numbers for the 25 years, the next step was to allow alignment of the ANB with the AB energy share coefficients for the base year 1977.

Recall the lag equation from the computer codes, in sub-routine GENEQ;

$AB(I,J) = AB(I,J)*[1.0-CA(J)] + CA(J)*ANB(I,J)$ or its form

$$B_{ij}(t+1) = (1-\mu_j)B_{ij}(t) + \mu_j B_{ij}^*(t)$$

Set the lag parameter CA(J) equal to zero, and adjust the DD cost share coefficients according to a procedure found to be acceptable, which is shown in Fig. 7.1 and described next.

As we can see in Fig. 7.1, there are two ways to adjust the DD coefficients. One is through the shares SH, and the other through the ANB coefficients. If we adjust using the SH, we have to consider a reference share $SH^{\sim}$ obtained from sources indicated in Fig. 6.2 to 6.5. If we adjust using the ANB, we need to consider the AB as reference obtained from the Energy Information Administration source.

A combined procedure was used since both sources are not necessarily consistent, and since the process needed to consider also the adjustment of the AIF coefficients obtained, in turn, from different sources, as was seen in section 6.2.

As a first step we derived an algorithm from the related mathematical expressions included in the demand module. The final formula is:

$$DD^{\sim}(NN)/DD^{\sim}(1) = \{[SH^{\sim}(NN)/SH^{\sim}(1)]/[SH(DD)/SH(1)]\} DD(NN)/DD(1)$$

where: $DD^{\sim}(NN)$ is the new cost share coefficient.

Argument (1) corresponds to the first quantity (first activity in each sector); in general it could be any of the activities.

An example of the last cycle of calculation, for each sector is presented in tables in Appendix H. The Lotus Spread

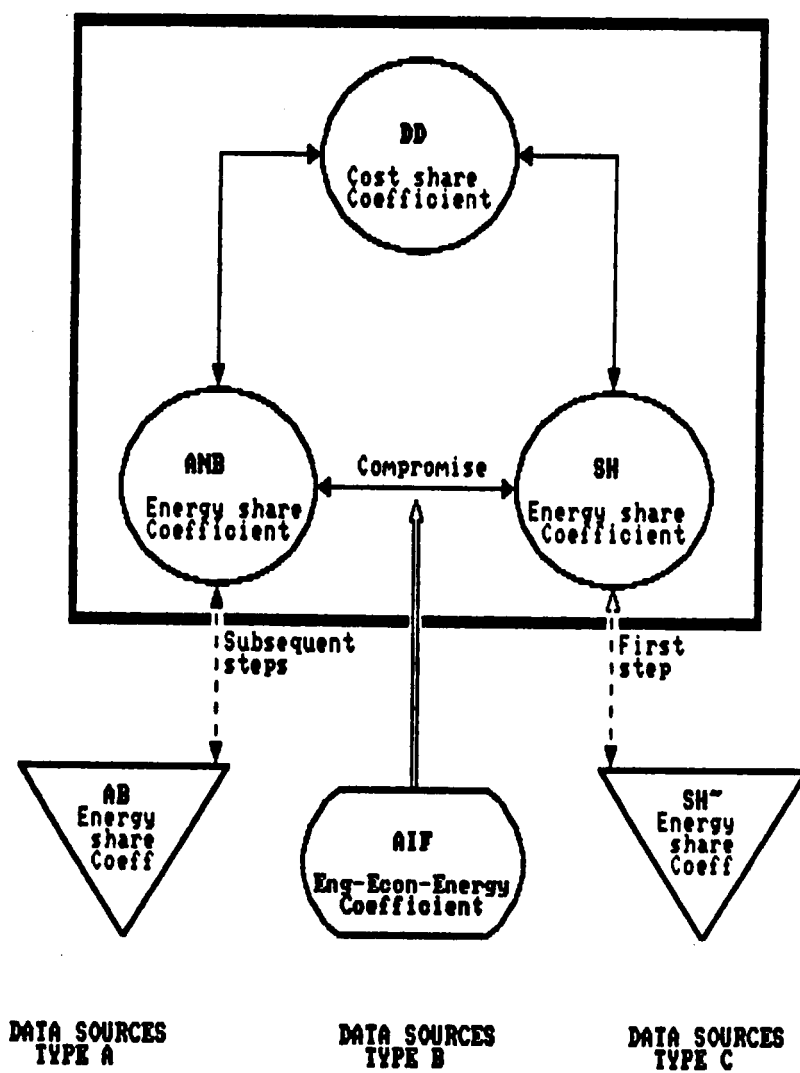


Fig. 7.1 Calibration Diagram

sheet was used as a convenient way of calculating.

A second step consisted of a series of calculations by successive stages of computation, approaching the ANB's to the AB's, by adjusting the DD's, and by changing the AIF's when it was strictly necessary.

The criterion for stopping was to match $ANB \approx AB$ over 95% in the significant fuels and services for each sector.

7.3 Validation

The model was validated considering the base year 1977 and three bench-references, the first year 1961, the last year 1985 and the critical energy year 1974.

First, the lag parameter was set to 0.2 . It is an estimate of the retarded effect on demand for each year. A similar value has been used in other models.

The model was run backward from 1977 to 1961. Each time adjustments were made in the indexed prices and fuel quantities of year 1961 in an effort to match the corresponding figures obtained from EIA sources shown in Appendix I.

The parameter that allows us to match the prices are the taxes for year 1961. The parameter used to match the energy quantities are the cost share coefficients DD's, and in the broad sense the price elasticities of demand RT's and the bounds Z's for the year 1961.

A similar procedure was adopted by running the model forward to try to match prices and energy quantities for 1985

Finally, the critical 1974 year was matched by the same procedure.

The model interpolates the price of capital PK, price of labor PL, the gross national product YT, the tax TX, the cost share coefficient DD and bound Z, when is not given for a year, "SUBROUTINE TERP called by SUBROUTINE INPRICE".

The validation procedure adopted gave reasonable results for the fuel in consideration as shown in Fig. 7.2.1 to Fig. 7.2.10, which compare each fuel demand with the historical data.

The electricity sector looks very good and the deviation in years 1969 to 1972 should decrease with full validation.

The crude oil sector was difficult to drive through a good path since it strongly depends on import of crude oil, and the model only considers the total imports. After an appropriate correction by tightening the bounds for E/O the curve improved in the right direction.

The model response to the natural gas well and natural gas transported sectors is very good. Improvement should be achieved for those intermediate years with a complete validation.

For the natural distributed sector, the response of the model is good except for the years 1979 to 1985, whose deviation is unexplained.

The fuel oil light sector looks quite good. Deviation in intermediate years should decrease with full validation.

The fuel oil heavy was a difficult sector to match because of the allocation of feedstock. The forward back-cast looks good enough, but the backward one does not.

The model response for the liquefied petroleum gas sector is acceptable, considering that this sector has three different origins of production: gas extraction at the well, at the industry itself and at the industrial process. Full validation should improve results.

The coal sector is difficult to match. Although prices agree over the long term in the industrial and utility processes, in the residential and commercial sectors prices obtained from different sources of data do not represent the availability of coal in different markets or the convenience of using it by the consumers. In spite of the above, the model reacts extremely well for the forward back-cast.

Finally, the model reacts poorly for the wood sector, probably the prices available from data for the sector do not represent real prices.

A comparison of indexed prices was obtained within the process of validation. A list of historical and model fuel prices is presented in Appendix J for those selected years 1961, 1974, 1977, 1985.

The process of validating a particular year is a very long one. In matching the indexed prices and the energy quantities for each energy sector, the adjustment on the taxes TX's and on the cost energy share coefficients DD's

need to be made by hand each time the program is run, since the fuels are related each other in a substitution or conservation mode, or both.

To obtain a reasonable validation for that particular year at least ten runs of the codes are needed. The CPU time for each run is 1.33 min. for the backward mode or 1.42 min. for the forward mode.

A full validation could consider bench-references every 2 years starting outward from the base year. Of course this is a very long process and will need a large data base, but the results should be much more close to the past figures.

A quantitative analysis to measure the error between the model data and historical data was performed for each fuel based on the root mean square error method (MSE).

[QBTU]	MSE	HIST. AVG.	(MSE)/(HIST.AVG.)
E	729.90	6151.46	0.12
CO	4165.62	24426.68	0.17
NG/W	1562.73	18391.12	0.08
NG/T	1549.48	18645.27	0.08
NG/D	1137.29	6906.70	0.16
FO/L	2046.65	19352.90	0.11
FO/H	2994.01	7618.84	0.39
LPG	328.20	1680.27	0.20
C	5211.64	14873.98	0.35
W	634.23	1743.74	0.36

ERROR=HIST.ENERGY-MODEL ENERGY

$MSE=[\sum (ERROR)^2/25]^{1/2}$

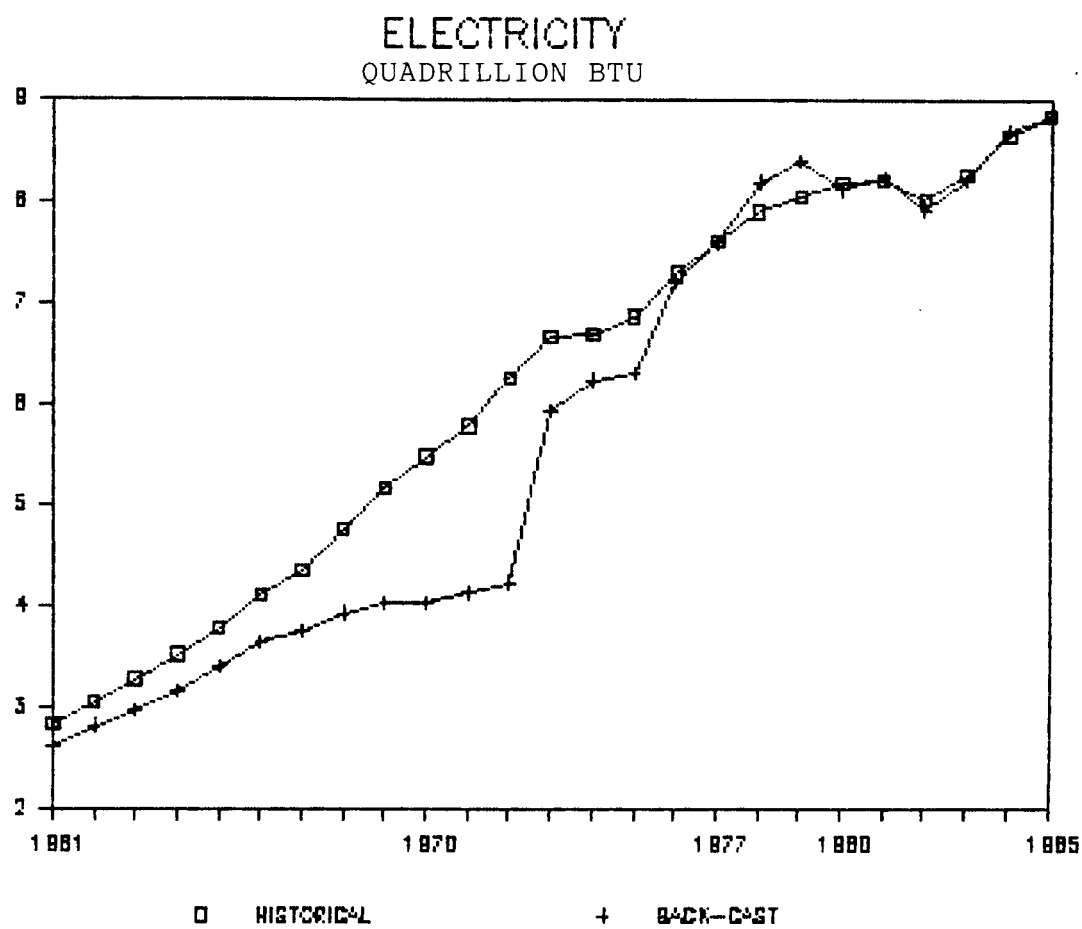


Fig. 7.2.1 Electricity Backcast

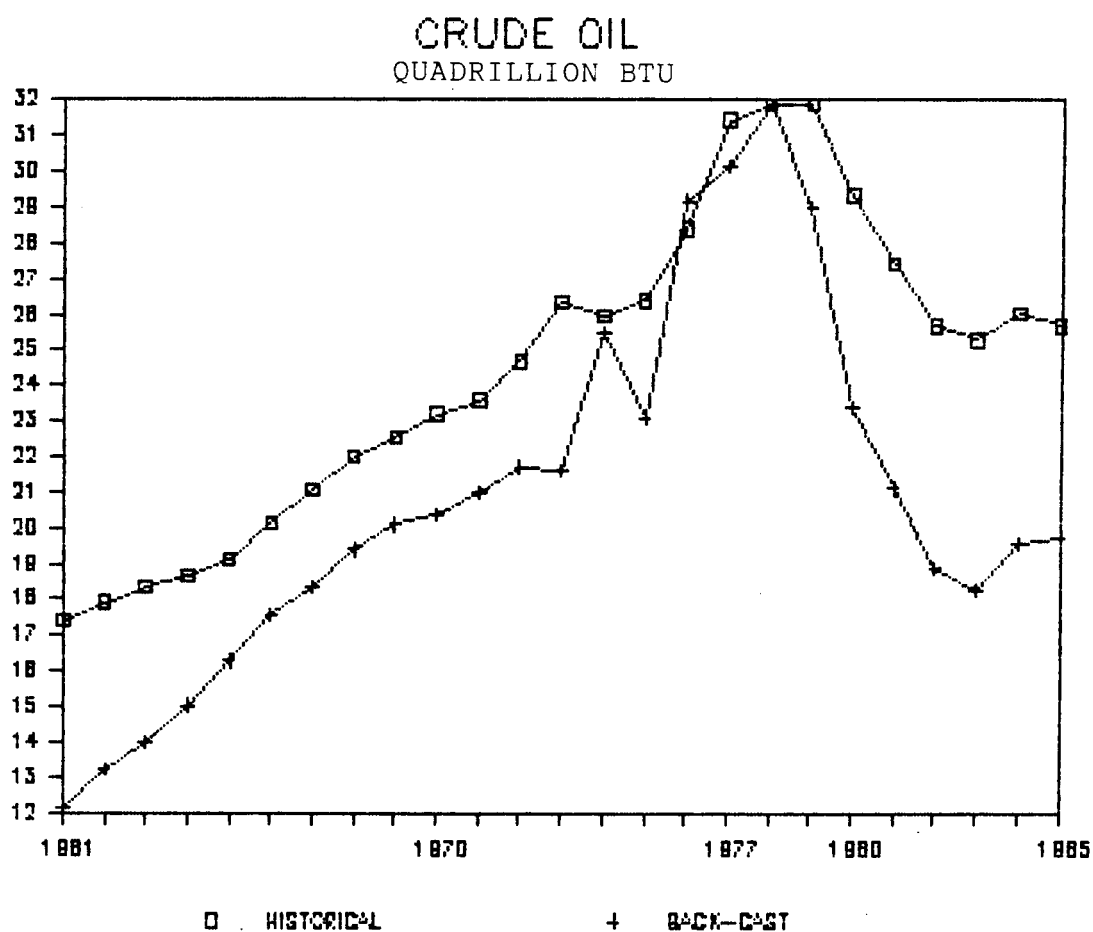


Fig. 7.2.2 Crude Oil Backcast

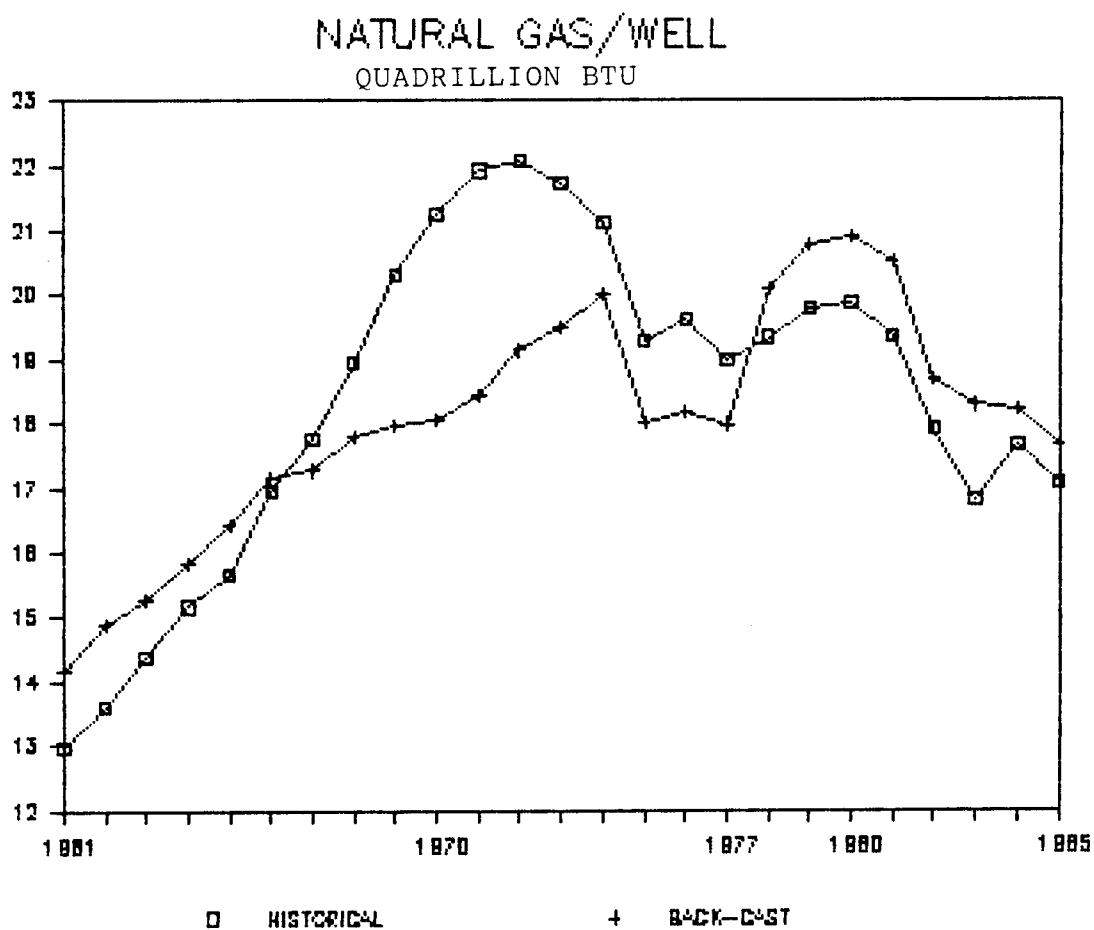


Fig. 7.2.3 Natural Gas/Well Backcast

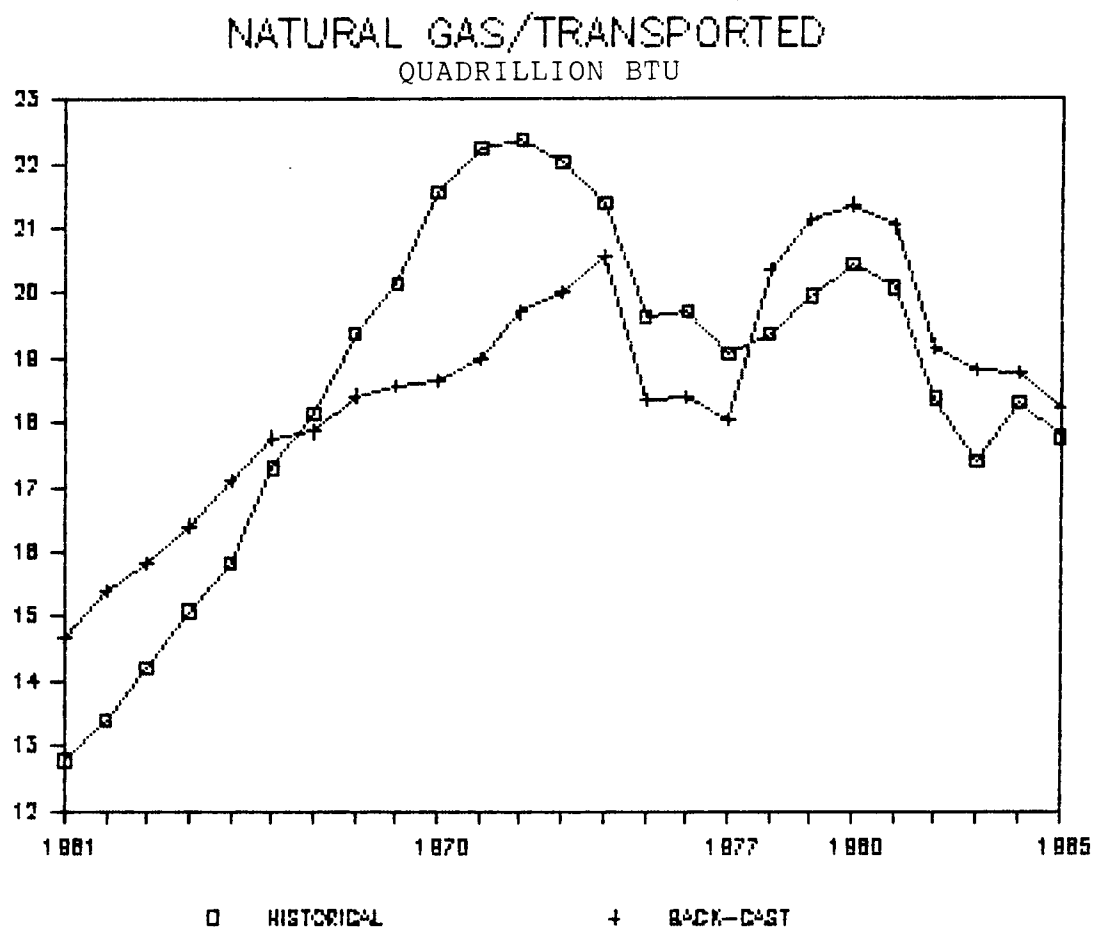


Fig. 7.2.4 Natural Gas/Transported Backcast

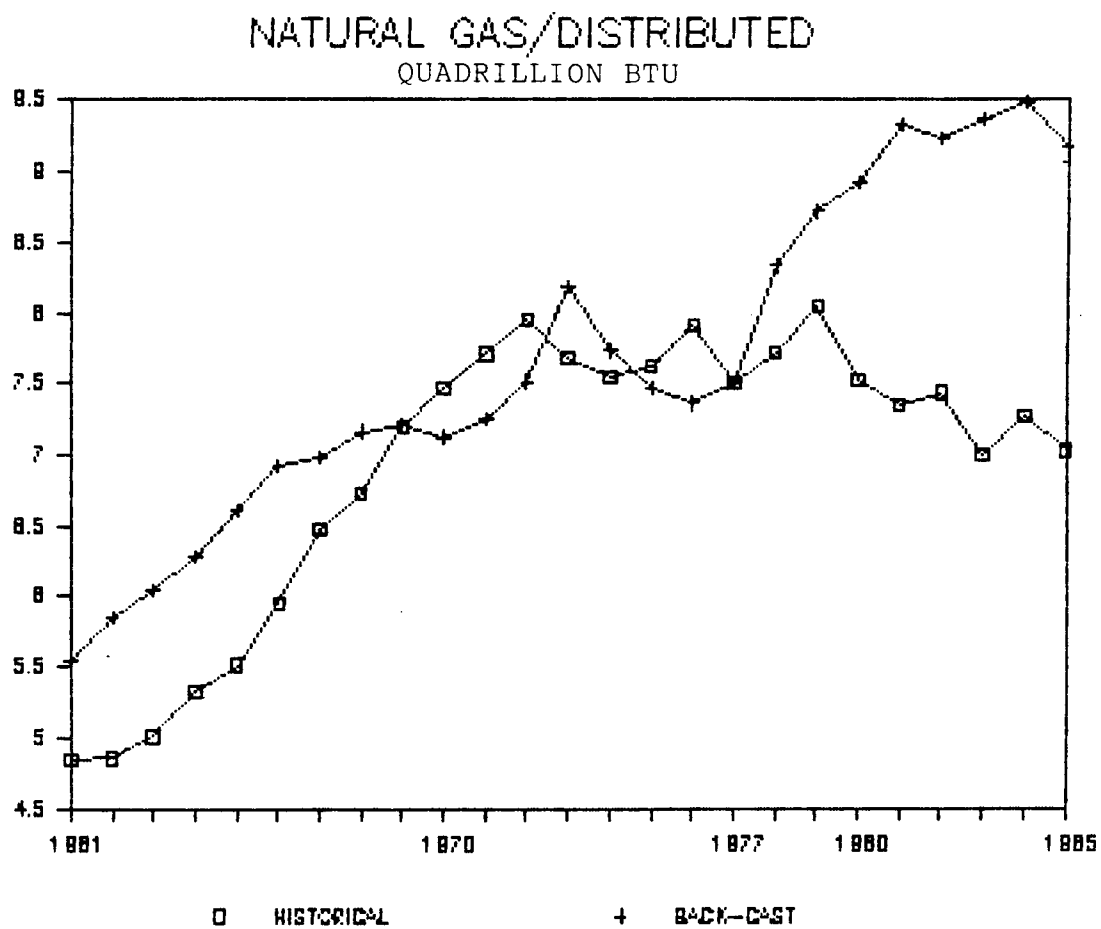


Fig. 7.2.5 Natural Gas/Distributed Backcast

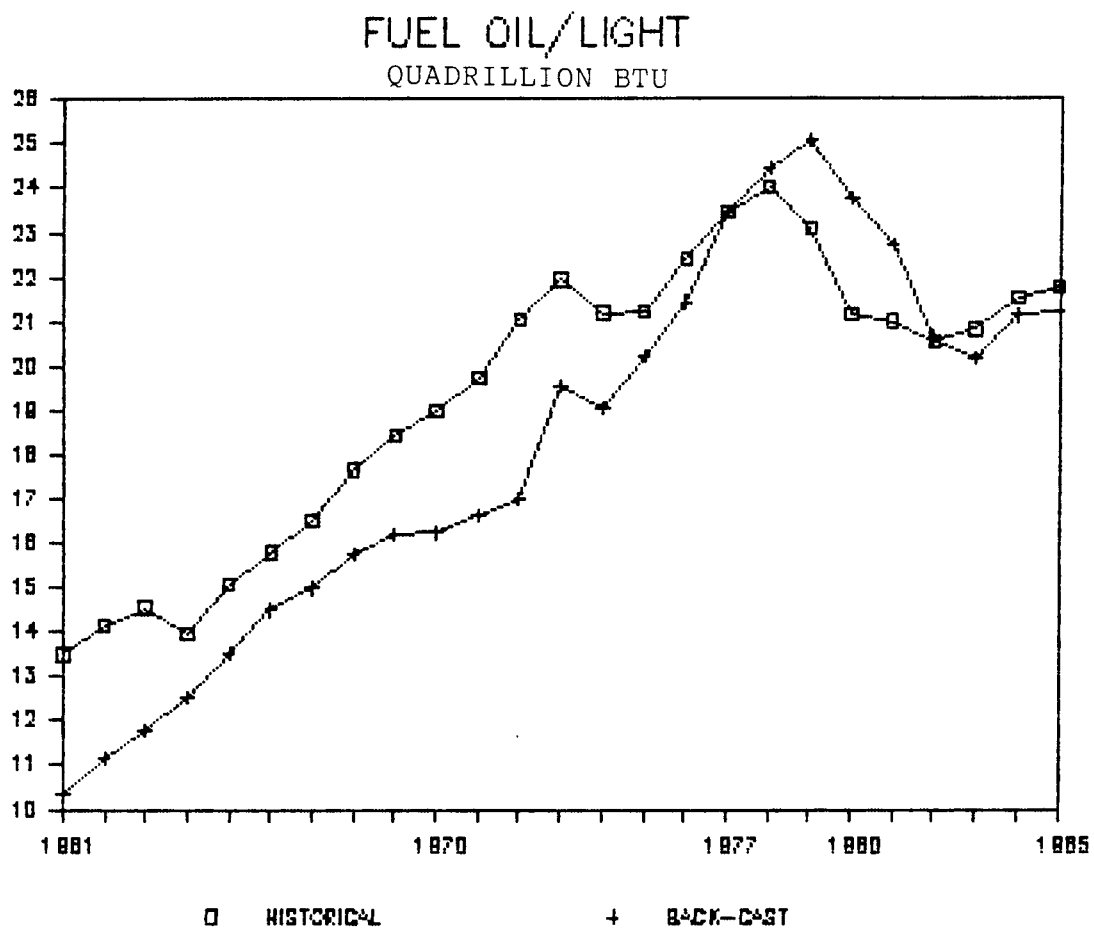


Fig. 7.2.6 Fuel Oil/Light Backcast

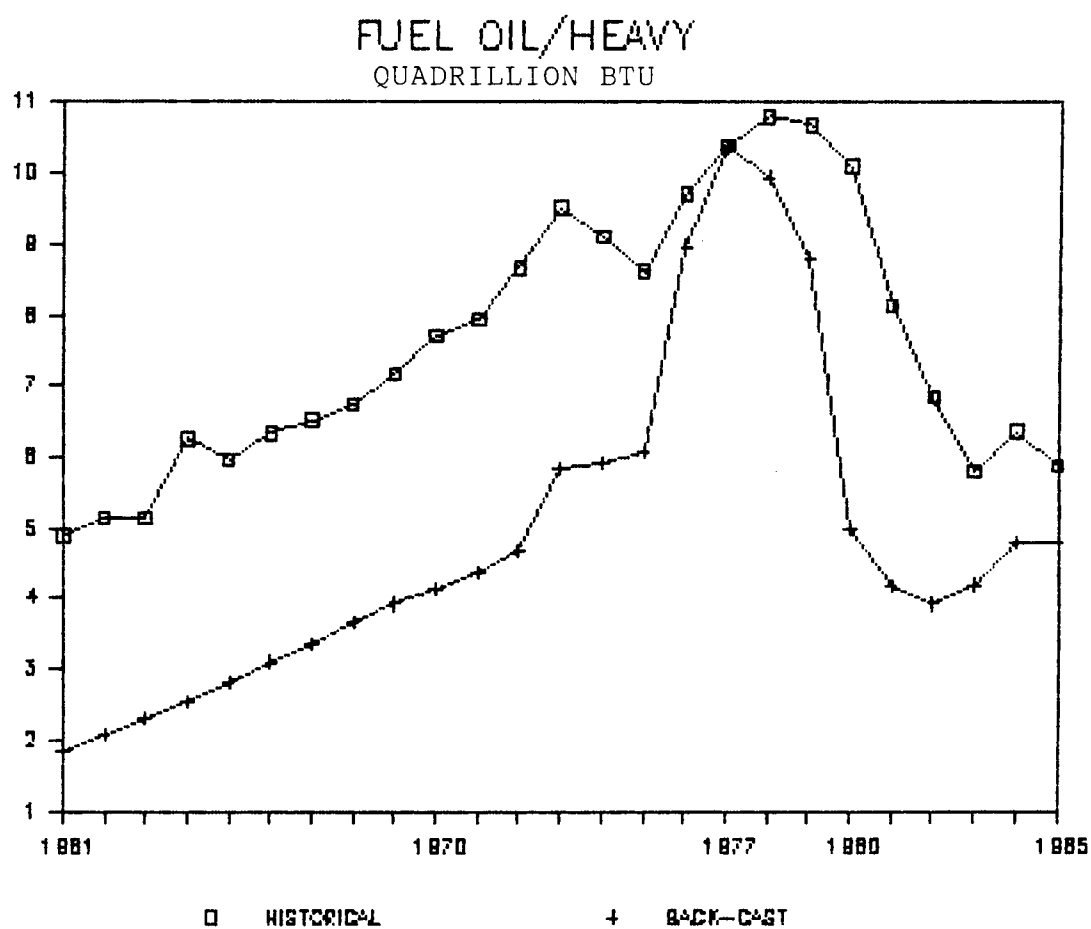


Fig. 7.2.7 Fuel Oil/Heavy Backcast

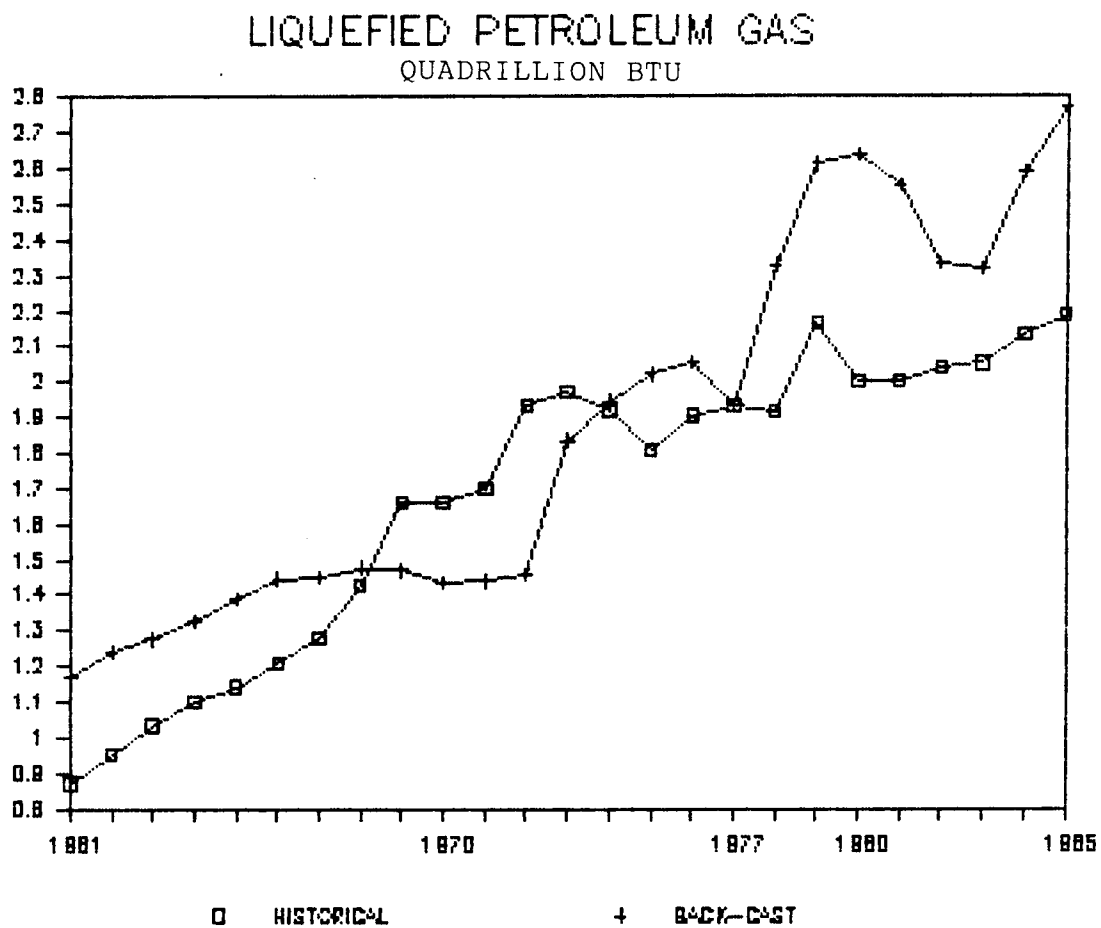


Fig. 7.2.8 Liquefied Petroleum Gas Backcast

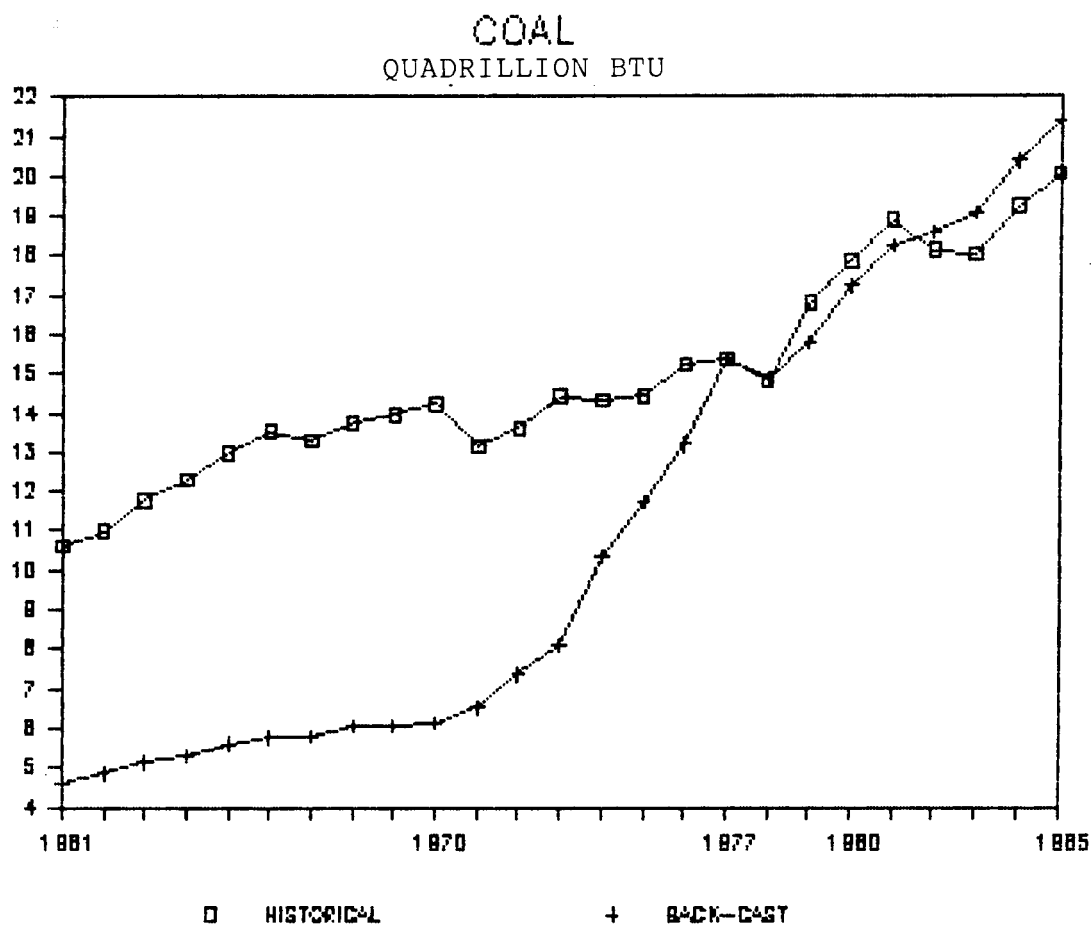


Fig. 7.2.9 Coal Backcast

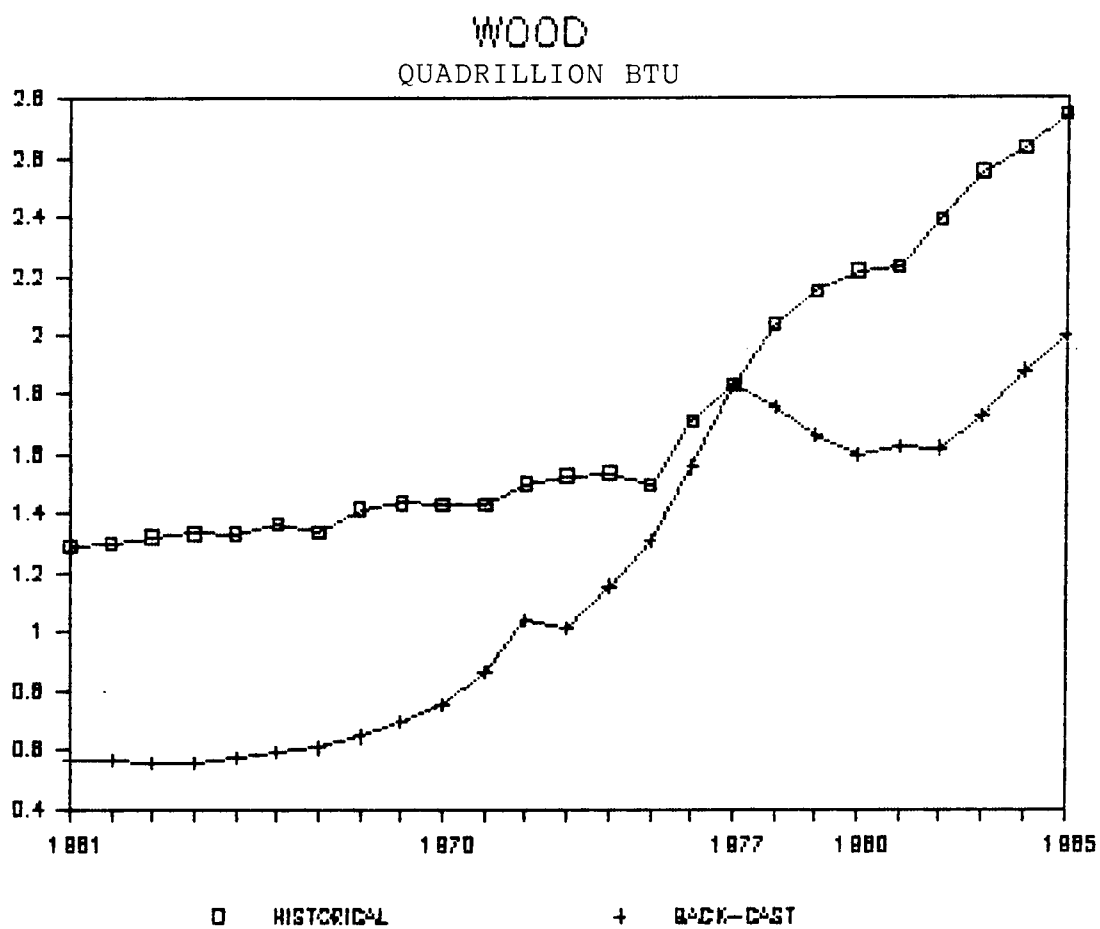


Fig. 7.2.10 Wood Backcast

CHAPTER 8

RESULTS AND FORECAST

8.1 Results

The validation of the GEM shows that the structure of the model contains the necessary ingredients to represent with a good approximation the energy demand-supply of a country.

For the U.S. data, the response to the demand of electricity, crude oil, natural gas well, natural gas transported, natural distributed, fuel oil light and liquefied petroleum gas are quite near to real figures. On the other side, the reaction of the model under crude oil, fuel oil heavy, coal and wood data produces a demand curve that responds properly to the changes in direction, but needs to be revised for possible errors in data to correct the magnitude of the deviations mentioned above.

The objective of this dissertation was to develop a model suitable for forecasting market penetration of energy supply technologies in a given country. The test employed U.S. data. The result is positive.

The primary purpose of the model was to focus its structure on market penetration applications. As was seen in Chapter 6, in the development of the engineering-economic-energy coefficients, the model structure was oriented to react under

the end-uses of energy. In the residential and commercial sectors where new technologies compete for the use of fuels, special emphasis was given to the electric heat pump and high efficiency gas burner. In the industrial sector, large units with high capacity factors were confronted with small units with low capacity factors. In the transportation sector the electric van vehicle and compressed natural gas fueled bus run against traditionally fueled versions.

Data available to develop the AIF coefficients came from different sources, and are not always consistent. Data to develop the I-O coefficients are commonly available in money quantities and need to be adjusted to energy quantities. Again we claim consistency with data used for the AIF coefficients.

A major effort should be made by a country, in structuring a good and consistent energy data base, to implement this model.

Realizing that a "milestone-path" could be useful to facilitate the improvement of this model (future versions) or to facilitate the understanding for developing another conceptual structure related to specific data for other countries, a "Short User's Guide" is presented in Appendix K. The best users guide, however, is the dissertation document as a whole.

8.2 Forecast

It was not the intention to forecast with the GEM at this first version, but as an illustration Fig. 8.1.1 to Fig. 8.1.10 show the projections of fuel demand-supply to year 2010.

The basic assumptions for this "forecasting" are as follow :

- Year 2010 correspond to NYR 50 of the model
- The PK's, PL's and TX's are the same as for NYR 25
- The GNP for NYR 50 was obtained by adding to the GNP of year 1985 a constant increment for 25 years, which correspond to the average increment of the past 25 years.
- The bounds Z placed on the processes for NYR 50 are not restrictive and follow at least the same mode adopted for the GNP.
- The GEM was run from 1977 to 2010.

By inspection of the curves, the following general conclusions follow:

- Electricity will grow at a higher rate than the crude oil.
- The demand-supply curve for natural gas will maintain almost the same shape for all three consumption stages.
- The rate of increase of the demand for fuel oil light will be greater than the corresponding rate

for fuel oil heavy and for liquefied petroleum gas.

- The demand for coal will stay almost linear.
- The demand for wood will be quite high for the first 10 years, dropping slightly its rate from there on.

Two additional illustrations are presented under the same above assumptions:

a) Electric Energy Supply Sources: Electricity-Hydro, Electricity-Nuclear, Electricity-Coal (see Fig. 8.2).

b) Scenario:

- In 1986 the price of crude oil is 15 [\$/BBL] and is maintained throughout 1990.
- In 1991 the price of crude oil is 40 [\$/BBL] and is maintained throughout 2010.

Indexed prices are calculated as follow:

$$I_p = (\text{assumed 1986 price}) / (\text{base 1977 price}) = 15 / 11.117 = 1.349$$

$$I_p = (\text{assumed 1991 price}) / (\text{base 1977 price}) = 40 / 11.117 = 3.598$$

The corresponding tax parameters are as follow:

$$\text{Tax}(1986 \text{ to } 1990) = 0.35$$

$$\text{Tax}(1991 \text{ to } 2010) = 2.60$$

A graph in term of energy differences for electricity, crude oil and natural gas well is presented in Fig. 8.3.

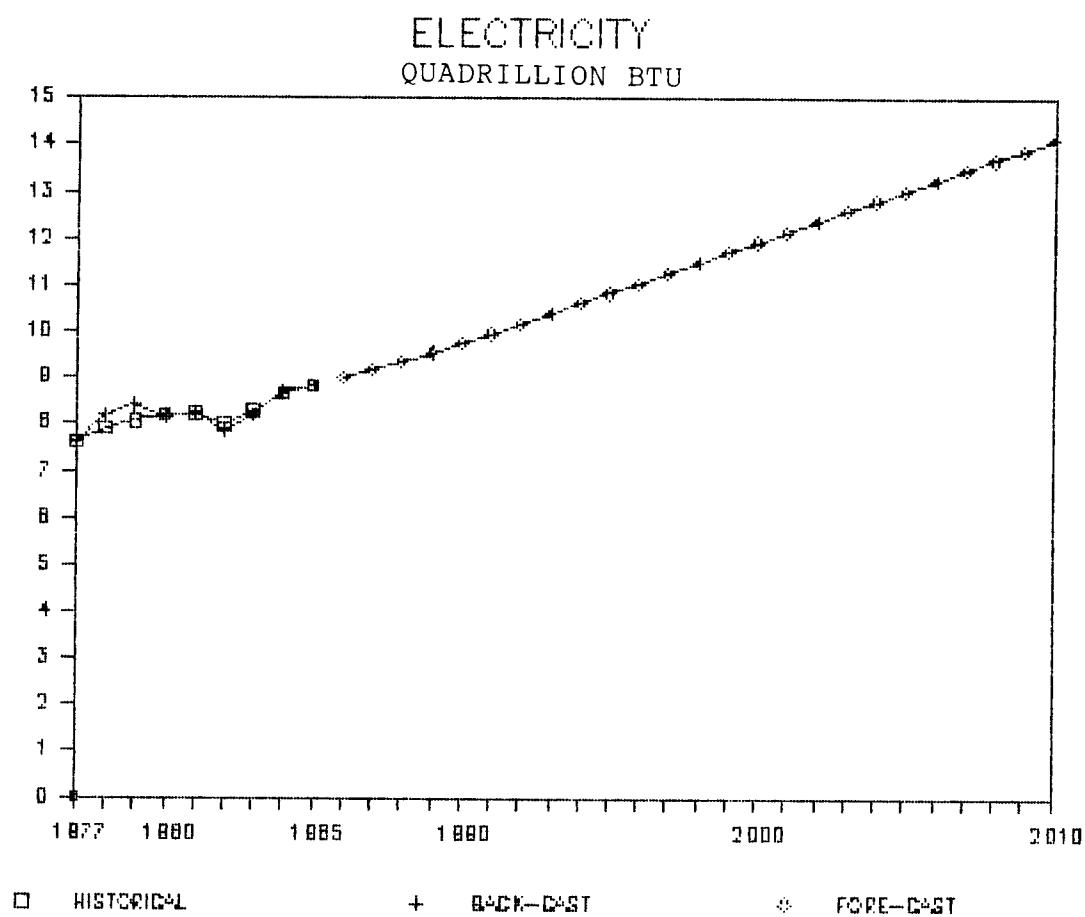


Fig. 8.1.1 Electricity Forecast

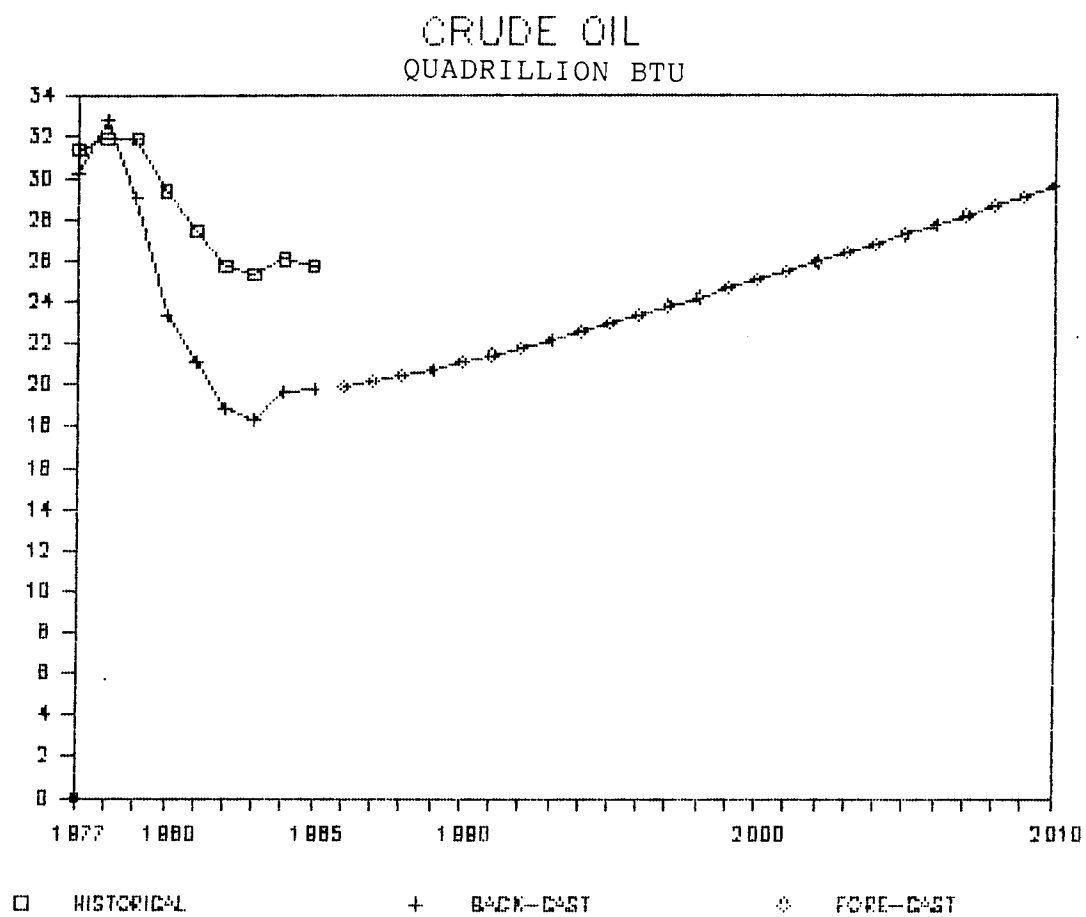


Fig. 8.1.2 Crude Oil Forecast

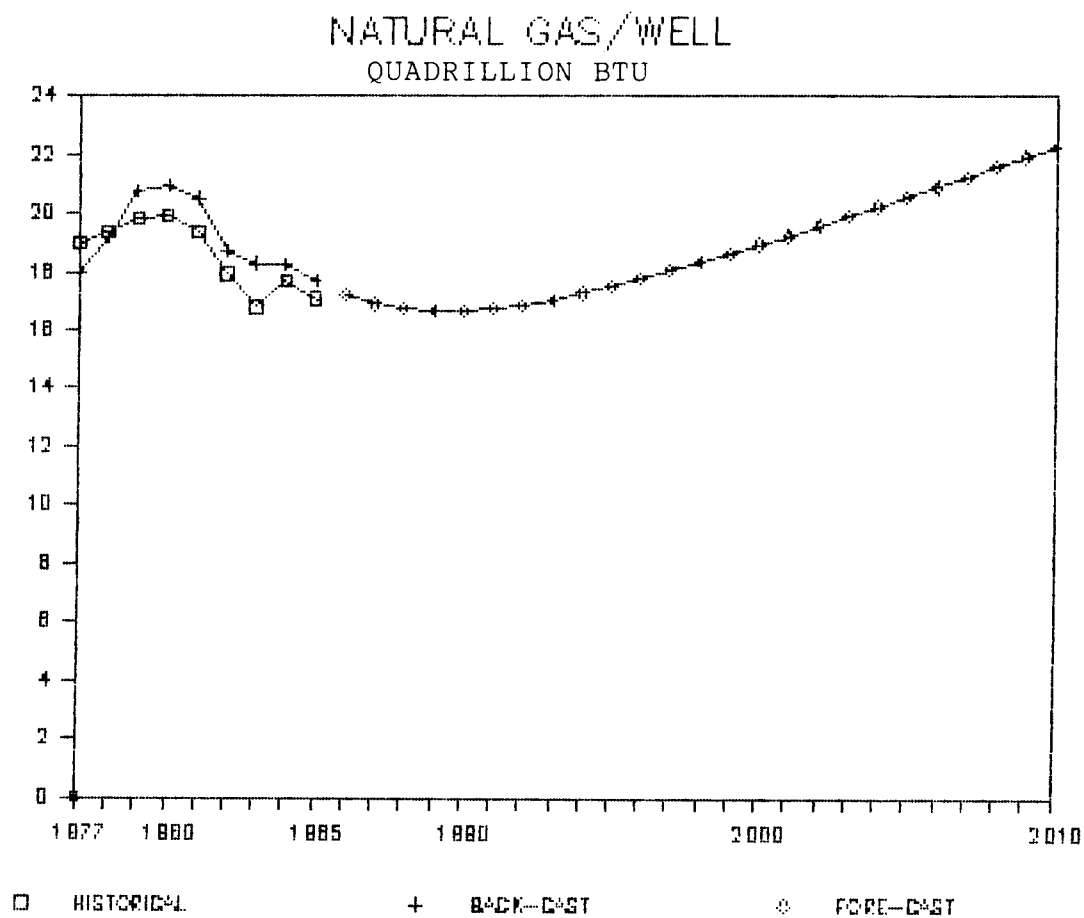


Fig. 8.1.3 Natural Gas/Well Forecast

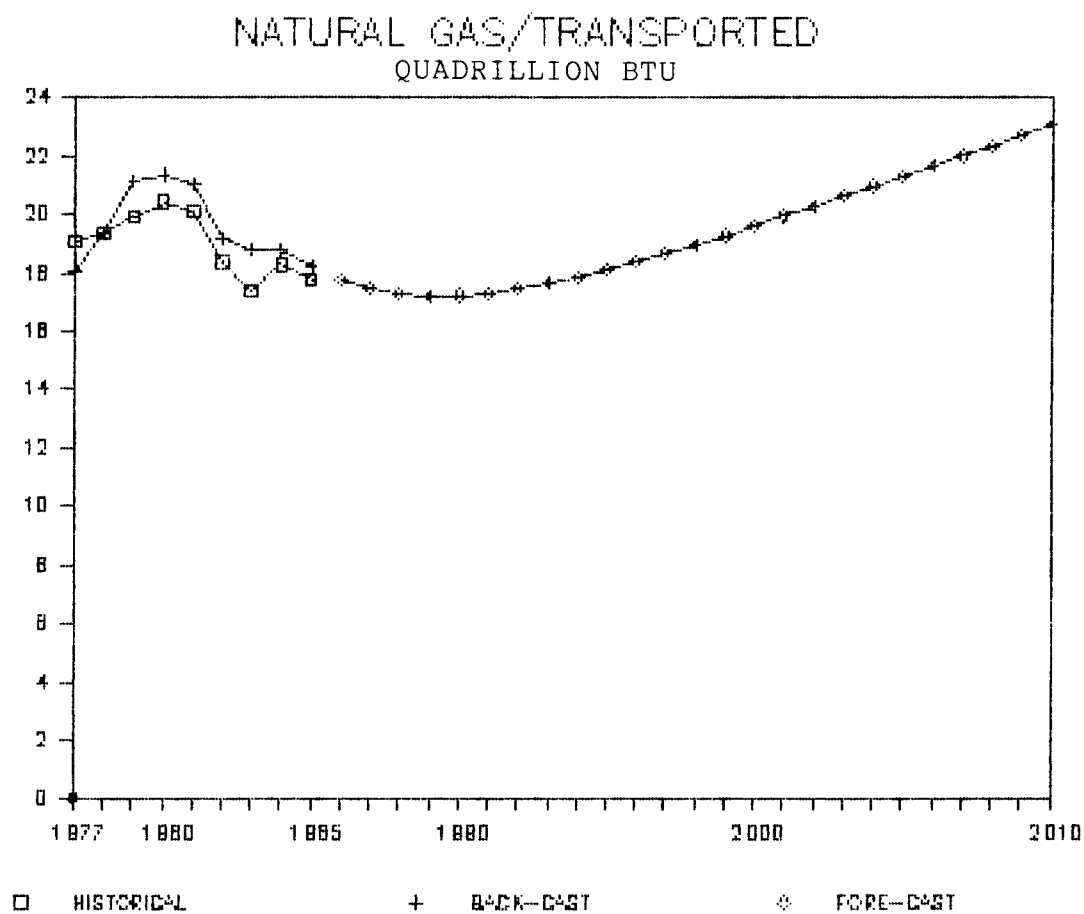


Fig. 8.1.4 Natural Gas/Transported Forecast

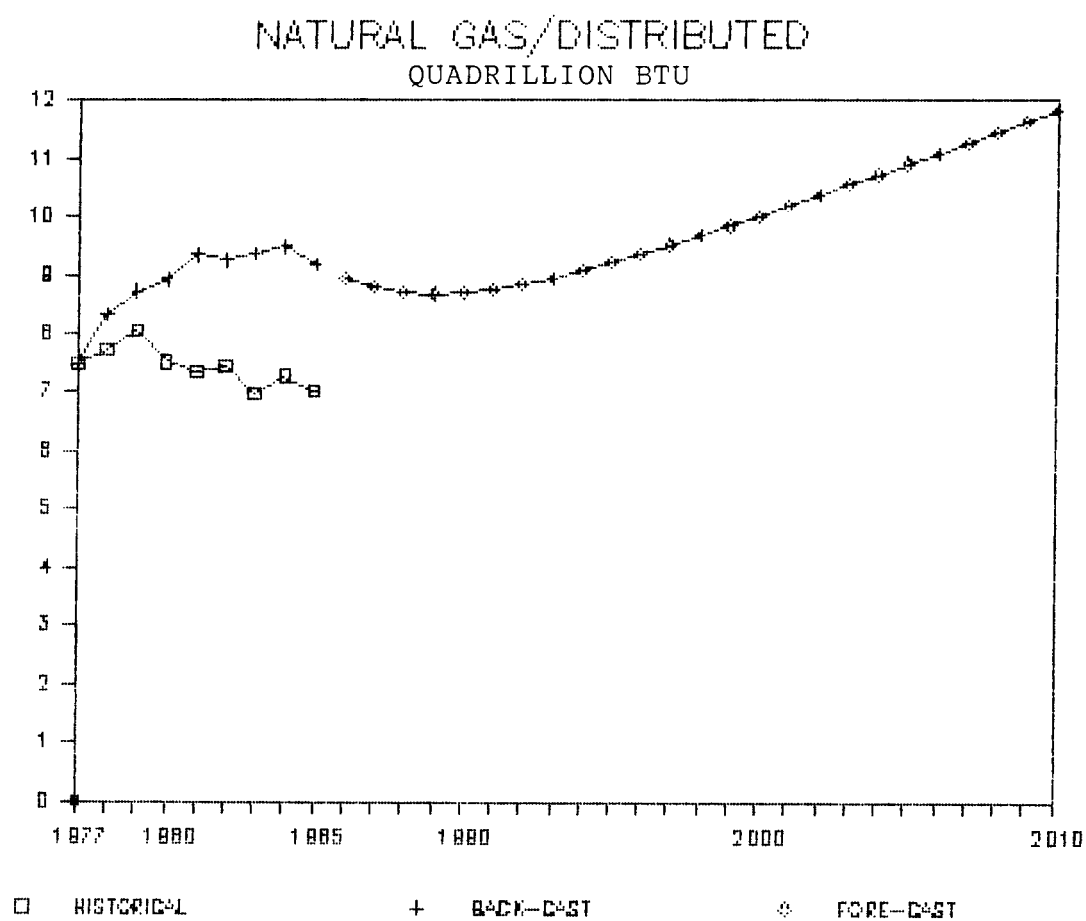


Fig. 8.1.5 Natural Gas/Distributed Forecast

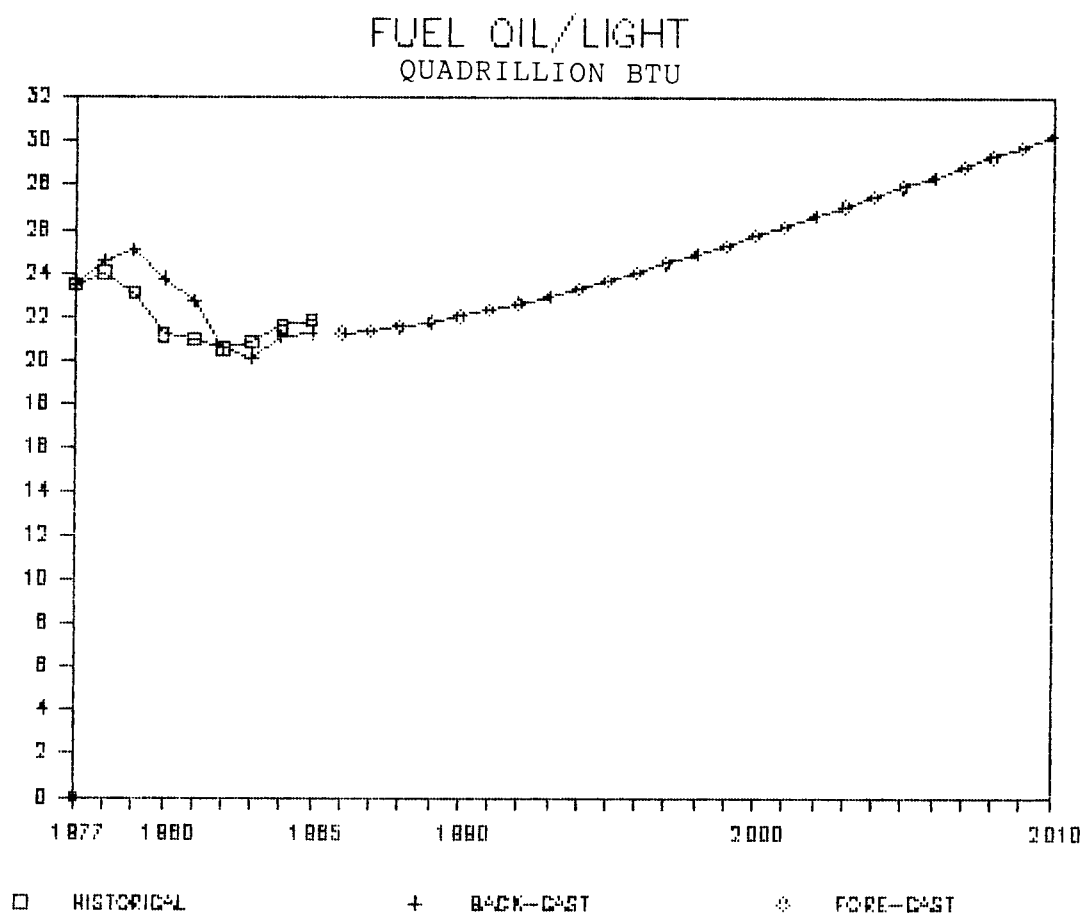


Fig. 8.1.6 Fuel Oil/Light Forecast

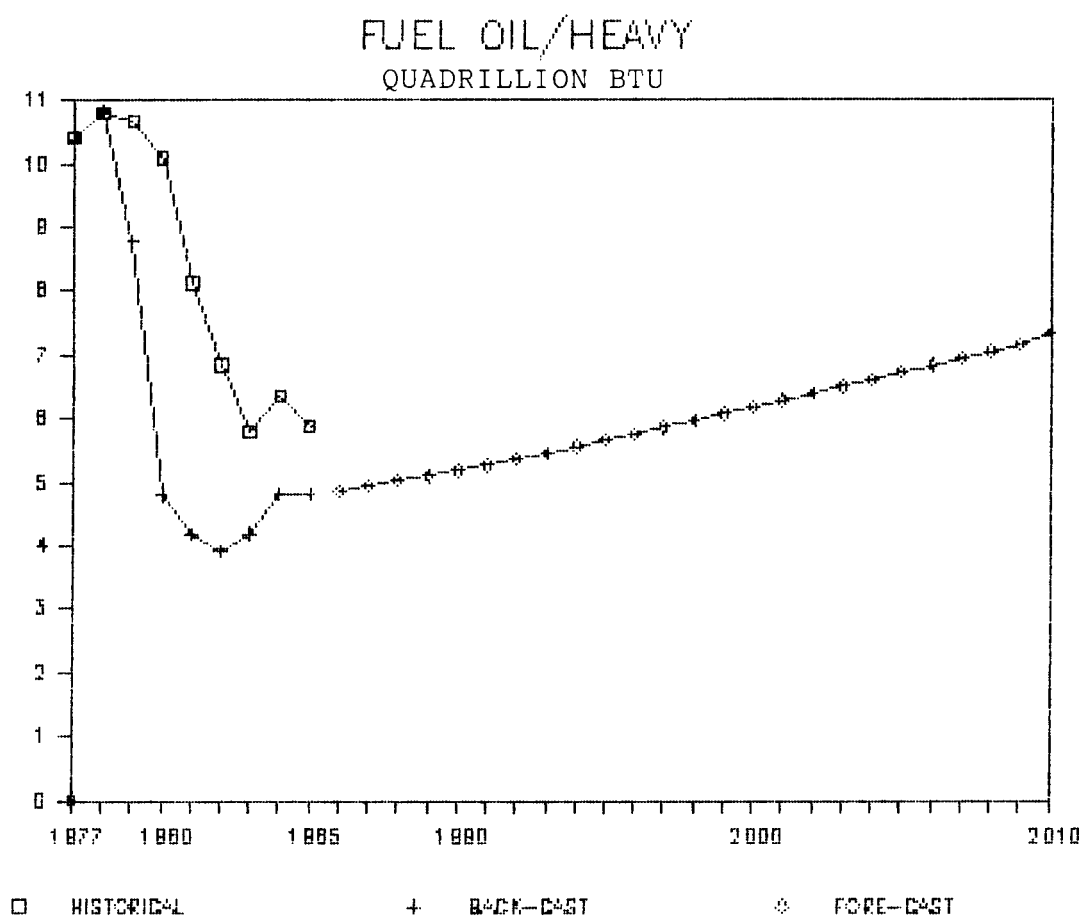


Fig. 8.1.7 Fuel Oil/Heavy Forecast

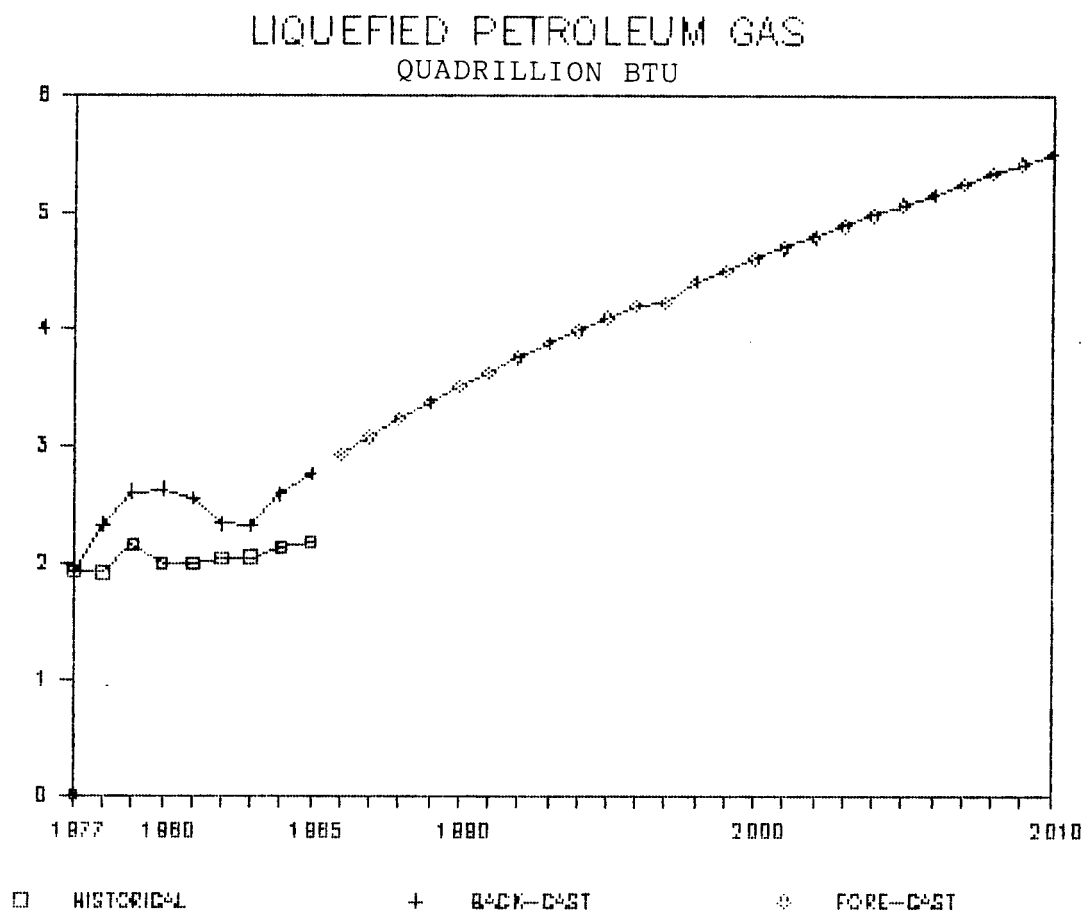


Fig. 8.1.8 Liquefied Petroleum Gas Forecast

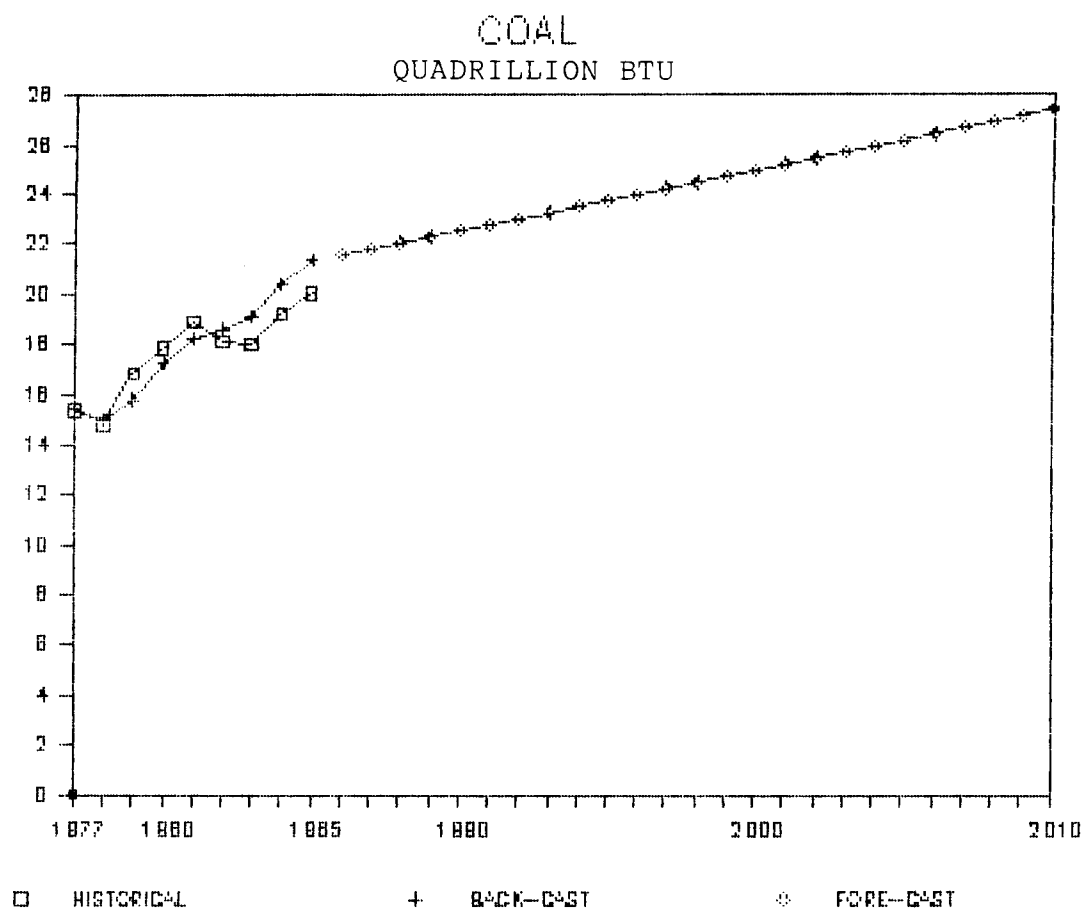


Fig. 8.1.9 Coal Forecast

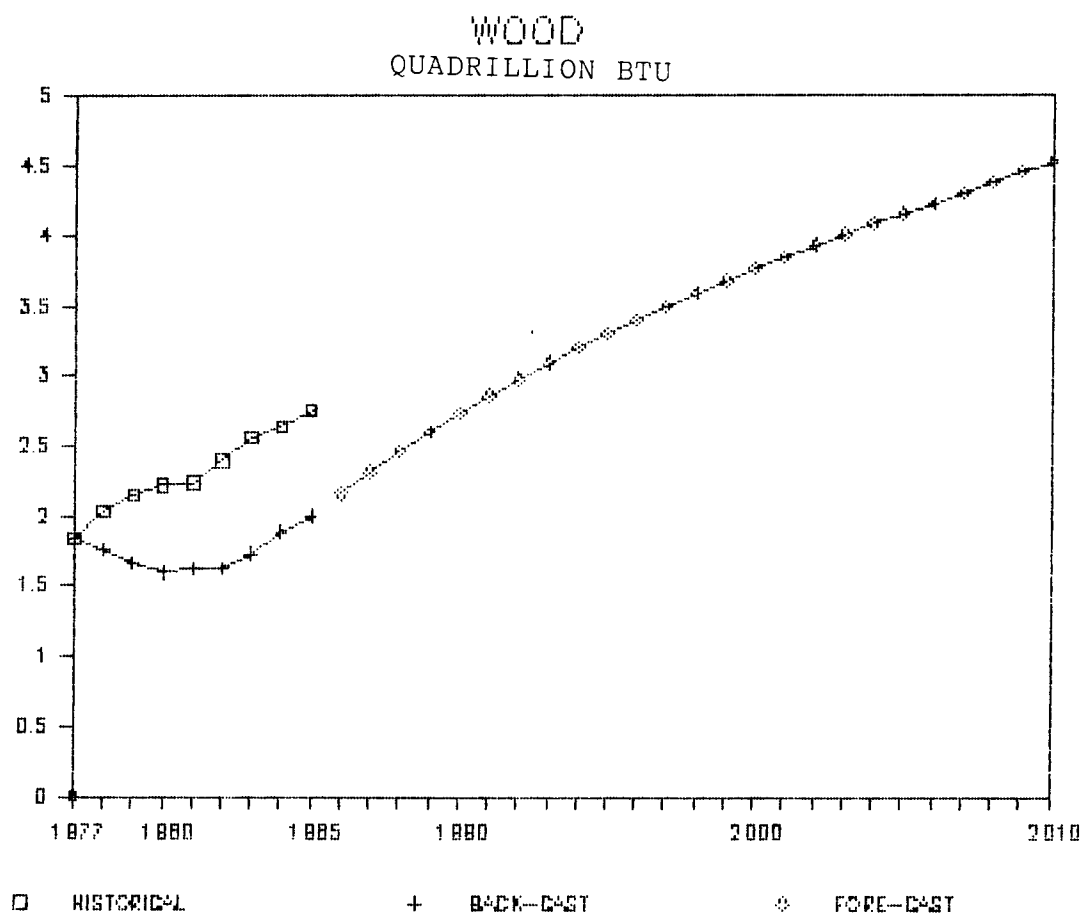


Fig. 8.1.10 Wood Forecast

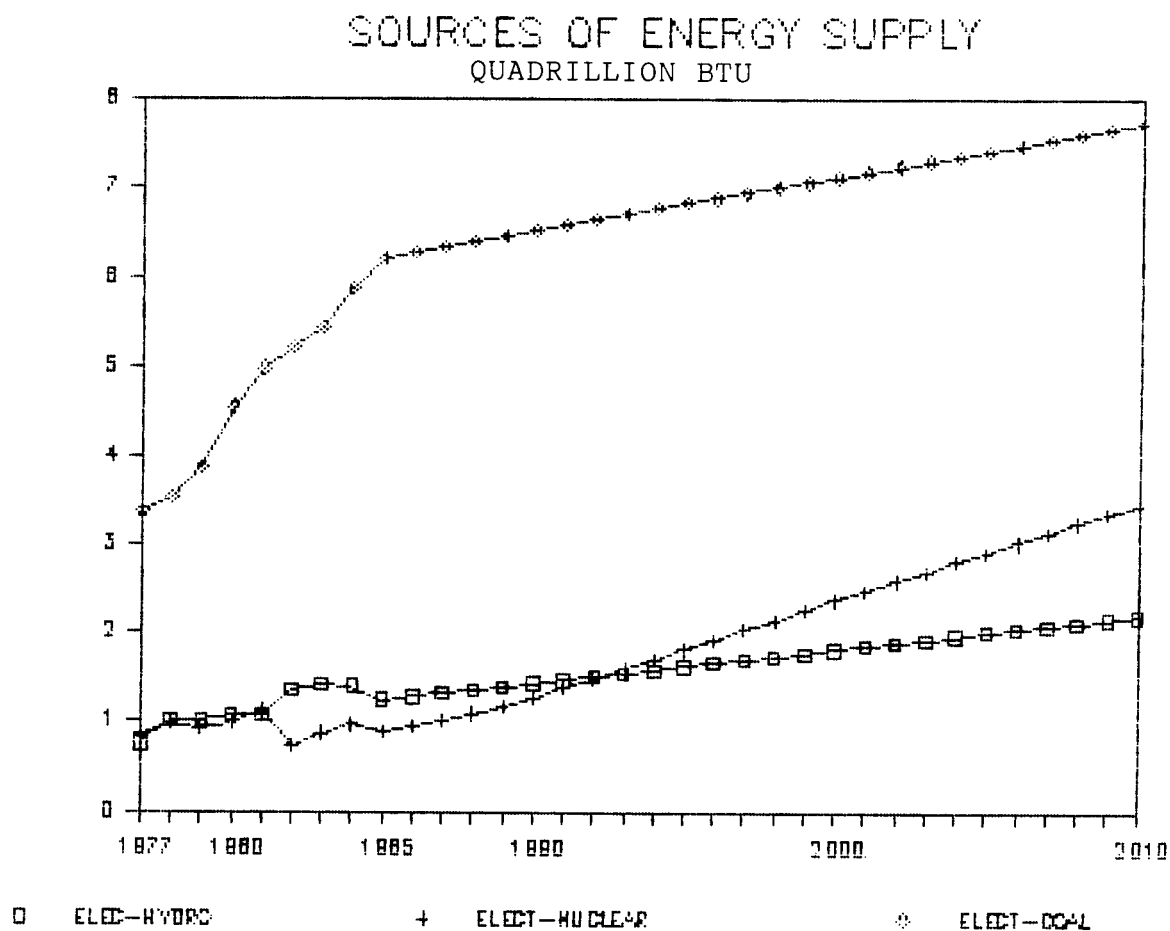


Fig. 8.2 Electric Energy Supply Sources Forecast

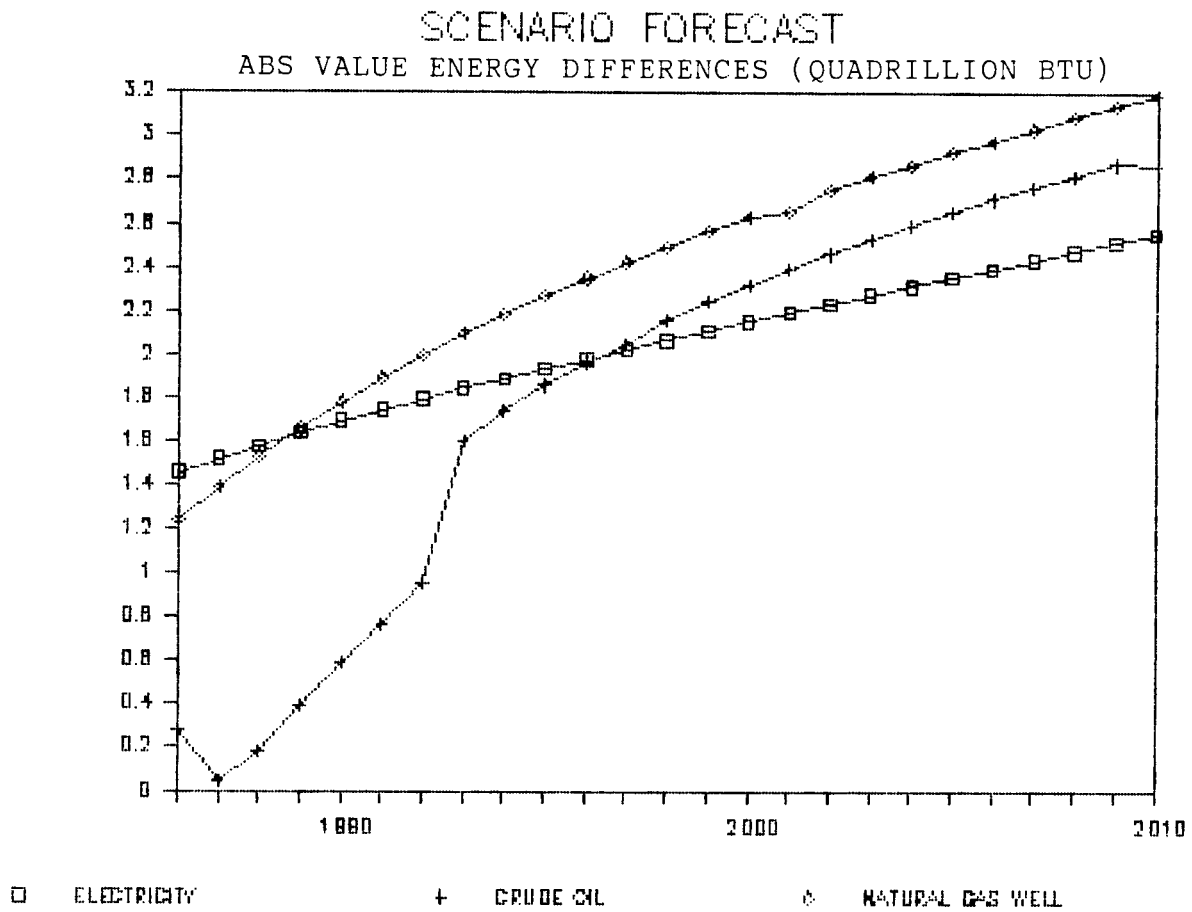


Fig. 8.3 Scenario Forecast

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APPENDIXES

APPENDIX A

FORTRAN PROGRAM

```

C
C   A GENERAL EQUILIBRIUM MODEL TO FORECAST MARKET
C   PENETRATION OF ENERGY SUPPLY TECHNOLOGIES
C
COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
C
KW=6
KV=8
CALL INDATA
C
CALL INPRIC
C
DO 100 I=1,NYR
DO 100 I=1,34
C
LT=18-I
LT=16+I
C
CALL GENEQ
C
IF(LT.EQ.NYR) STOP 5
IF(LT.EQ.1) STOP 6
C
CALL SUPPLY
C
CALL DEMAND
C
CALL FINAL
C
100 CONTINUE
C
STOP
C
END
BLOCK DATA
COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
DATA NGD,NYR,NSUP,NFU/14,50,20,10/
DATA NUMN,NUMNN/5,22,18,37,18,4/
END
SUBROUTINE INDATA
DIMENSION KA(6),ZA(6)
COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
COMMON /INPT/ AB(16,40),AA(16,40),YA(16),CY,COL(5,40),ROW(5,16),
1 CA(40),HEAD(10),BPFU(10),AIF(16,5,50,15),RN(5),RT(5),RY
COMMON /EQLB/ ANB(16,40),YNA(16)
C
NFACT=NGD+2
NM=NSUP+NUMN

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NMT=NM+2
NMY=NM+1
NFUT=NFU+1

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C

```

DO 3 M=1,NFACT
DO 3 J=1,NM
3 ANB(M,J)=0.0
DO 5 L=1,NYR
5 NYEAR(L)=L+1960
READ ( 5,900) HEAD
DO 10 J=1,NMT
10 READ ( 5,900) (COL(K,J),K=1,5)
900 FORMAT (10A4)
DO 15 I=1,NFACT
15 READ ( 5,900) (ROW(K,I),K=1,5)
READ ( 5,901) (RN(I),I=1,5)
READ ( 5,901) RY,(RT(I),I=1,5)
READ ( 5,901) (BPFU(I),I=1,NFU)
901 FORMAT (7F9.0)
READ ( 5,901) CY,(CA(J),J=1,NM)
READ ( 5,901) (YA(I),I=1,NGD)
READ ( 5,902) NZ,(JZ(I),I=1,16)
DO 17 N=1,NUMN
NNL=NUMNN(N)
17 READ ( 5,902) (NUMNI(N,K),K=1,NNL)
DO 20 J=1,NM
READ ( 5,901) (AA(I,J),I=1,NGD)
20 READ ( 5,901) (AB(I,J),I=1,NFACT)
DO 25 N=1,NUMN
NNL=NUMNN(N)
DO 25 NN=1,NNL
NIL=NUMNI(N,NN)
DO 25 NI=1,NIL
DO 22 I=1,NFACT
22 AIF(I,N,NN,NI)=0.0
READ ( 5,903) (KA(I),ZA(I),I=1,6)
DO 24 I=1,6
LL=KA(I)
IF(LL.LE.0) GO TO 24
AIF(LL,N,NN,NI)=ZA(I)
24 CONTINUE
25 CONTINUE
903 FORMAT(6(I2,F8.0))
READ ( 5,902) NEND
902 FORMAT (15I4)
IF (NEND.NE.9999) STOP 8
SUM=0.0
DO 30 I=1,NGD
30 SUM=SUM+YA(I)
DO 35 I=1,NGD
35 YA(I)=YA(I)/SUM
DO 55 J=1,NM
SUM=0.0
DO 40 I=1,NFACT

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```

40 SUM=SUM+AB(I,J)
   DO 45 I=1,NFACT
45 AB(I,J)=AB(I,J)/SUM
   DO 50 I=1,NGD
50 AA(I,J)=AA(I,J)/SUM
55 CONTINUE
   AA(1,1)=AA(1,1)*1.001
   AA(1,2)=AA(1,2)*1.0009
   AA(1,3)=AA(1,3)*1.0008
   AA(1,4)=AA(1,4)*1.0
   AA(1,5)=AA(1,5)*1.0007
   AA(1,6)=AA(1,6)*1.0006
   AA(2,7)=AA(2,7)*0.999
   DO 60 J=1,NM,4
   JA=J+3
   IF(JA.GT.NM) JA=NM
   WRITE (KW,905) (JJ,(COL(L,JJ),L=1,4),JJ=J,JA)
905 FORMAT(10X,'OUTPUT AA AND INPUT AB VECTORS'/26X,4(I6,2X,4A4)/
1 26X,4(10X,'AA',10X,'AB'))
   DO 60 I=1,NFACT
   60 WRITE (KW,906) I,(ROW(L,I),L=1,4),(AA(I,JJ),AB(I,JJ),JJ=J,JA)
906 FORMAT(I8,2X,4A4,8F12.6)
   RETURN
   END
   SUBROUTINE INPRIC
   COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
   COMMON /PRICE/ PK(50),PL(50),TX(40,50),YT(50),PP(16),DD(5,50,50),
1 DF(16,50),Z(40,50)
   DIMENSION ZA(5),KA(5),DA(50,50)
   DO 200 LL=1,NYR
   PK(LL)=0.0
   PL(LL)=0.0
   YT(LL)=0.0
   DO 110 I=1,NM
110 TX(I,LL)=0.0
   DO 120 I=1,NGD
120 DF(I,LL)=0.0
   DO 130 I=1,NZ
130 Z(I,LL)=0.0
200 CONTINUE
   5 READ ( 5,900) KB,(KA(K),ZA(K),K=1,5)
900 FORMAT(I3,5(I4,F8.0))
   IF(KB.LE.0) GO TO 22
   DO 20 K=1,5
   KK=KA(K)
   IF(KK.LE.0) GO TO 5
   GO TO (10,12,14),KB
10 PK(KK)=ZA(K)
   GO TO 20
12 PL(KK)=ZA(K)
   GO TO 20
14 YT(KK)=ZA(K)
20 CONTINUE

```

```

      GO TO 5
22  CONTINUE
      CALL TERP (PK,1,50,NYR,1)
      CALL TERP (PL,1,50,NYR,1)
      CALL TERP (YT,1,50,NYR,1)
25  READ ( 5,900) KB,(KA(K),ZA(K),K=1,5)
      IF(KB.LE.0) GO TO 32
      DO 30 K=1,5
      KK=KA(K)
      IF(KK.LE.0) GO TO 25
30  TX(KB,KK)=ZA(K)
      GO TO 25
32  CONTINUE
      CALL TERP (TX,40,50,NYR,NM)
      DO 44 N=1,NUMN
     >NNL=NUMNN(N)
      DO 33 NN=1,NNL
      DO 33 LL=1,NYR
33  DA(NN,LL)=0.0
35  READ ( 5,900) KB,(KA(K),ZA(K),K=1,5)
      WRITE(KV,902) KB,(KA(K),ZA(K),K=1,5)
902 FORMAT(I10,5(I4,F10.6))
      IF(KB.LE.0) GO TO 42
      DO 40 K=1,5
      KK=KA(K)
      IF(KK.LE.0) GO TO 35
40  DA(KB,KK)=ZA(K)
      GO TO 35
42  CONTINUE
      SUM=0.0
      DO 41 NN=1,NNL
41  SUM=SUM+DA(NN,17)
      WRITE(KV,901) N,SUM
901 FORMAT(10X,'N=',I2,5X,'SUM OF DD=',F10.6)
      CALL TERP (DA,50,50,NYR,NNL)
      DO 43 NN=1,NNL
      DO 43 LL=1,NYR
43  DD(N,NN,LL)=DA(NN,LL)
44  CONTINUE
45  READ ( 5,900) KB,(KA(K),ZA(K),K=1,5)
      IF(KB.LE.0) GO TO 52
      DO 50 K=1,5
      KK=KA(K)
      IF(KK.LE.0) GO TO 45
50  DF(KB,KK)=ZA(K)
      GO TO 45
52  CONTINUE
      CALL TERP (DF,16,50,NYR,NGD)
910 FORMAT(I3,I4,F9.0,4(I3,F9.0))
55  READ ( 5,910) KB,(KA(K),ZA(K),K=1,5)
      IF(KB.LE.0) GO TO 62
      DO 60 K=1,5
      KK=KA(K)
      IF(KK.LE.0) GO TO 55

```

```

60 Z(KB, KK)=ZA(K)
   GO TO 55
62 CONTINUE
   CALL TERP (Z, 40, 50, NYR, NZ)
   RETURN
   END
   SUBROUTINE GENEQ
     COMMON /BLKN/ NGD, NFACT, NKL, NYR, NSUP, NM, NYEAR(50), NZ, JZ(40)
     1 , LT, NTYPE, NMT, NMY, NFU, NFUT, NUMN, NUMNN(5), NUMNI(5, 50), KW, KV
     COMMON /INPT/ AB(16, 40), AA(16, 40), YA(16), CY, COL(5, 40), ROW(5, 16),
     1 CA(40), HEAD(10), BPFU(10), AIF(16, 5, 50, 15), RN(5), RT(5), RY
     COMMON /PRICE/ PK(50), PL(50), TX(40, 50), YT(50), PP(16), DD(5, 50, 50),
     1 DF(16, 50), Z(40, 50)
     COMMON /EQLB/ ANB(16, 40), YNA(16)
     DIMENSION V(60), Y(16), XA(60, 60), XB(60), XC(40), PSOL(60), DSOL(60),
     1 RW(3600), IW(180), VA(40), VXP(40), EA(15, 40), EB(15, 40), GZ(4)
     DOUBLE PRECISION XA, XB, XC, SS, PSOL, DSOL, RW
C
C   CALCULATE THE MATRIX ELEMENTS
C
   IF(LT.NE.16) GO TO 7
C
   NR=NSUP+1
   WRITE (KV, 911) ((COL(L, J), L=1, 5), J=NR, NM)
911 FORMAT(1H1, 35X, 22A4)
   DO 5 I=1, NFACT
     5 WRITE (KV, 912) I, (ROW(L, I), L=1, 5), (ANB(I, J), J=NR, NM)
912 FORMAT(10X, I3, 2X, 5A4, 5(F12.6, 8X))
   7 CONTINUE
   IF(LT.EQ.17) GO TO 20
   DO 10 I=1, NFACT
     DO 10 J=1, NM
     10 AB(I, J)=AB(I, J)*(1.0-CA(J))+CA(J)*ANB(I, J)
     DO 15 I=1, NGD
     15 YA(I)=YA(I)*(1.0-CY)+CY*YNA(I)
     20 CONTINUE
     DO 25 I=1, NGD
     25 Y(I)=YA(I)*YT(LT)
     DO 30 J=1, NM
     30 V(J)=PK(LT)*AB(15, J)+PL(LT)*AB(16, J)+TX(J, LT)
     PLW=0.3*PK(LT)
C
C   SET UP THE LP
C
   NN=NGD+NZ
   DO 35 I=1, NZ
     DO 35 J=1, NM
     35 XA(I+NGD, J)=0.0
     DO 40 J=1, NM
     DO 40 I=1, NGD
     40 XA(I, J)=AB(I, J)-AA(I, J)
     DO 45 I=1, NGD
     45 XB(I)=-Y(I)
     DO 50 II=1, NZ

```

```

      J=JZ(II)
      XA(II+NGD,J)=1.0
50  XB(II+NGD)=Z(II,LT)
      DO 55 J=1,NM
55  KC(J)=-V(J)
      IF(LT.GT.-1) GO TO 200
      WRITE (KW,913) (J,XC(J),J=1,NM)
913  FORMAT(9(I4,F10.6))
      WRITE (KW,915) (I,XB(I),I=1,NN)
915  FORMAT(9(I4,F10.2))
      DO 110 I=1,NN
110  WRITE (KW,914) (I,J,XA(I,J),J=1,NM)
914  FORMAT (7(2I4,F10.6))
200  CONTINUE

C      CALL ZX4LP(XA,60,XB,XC,NM,NN,0,SS,PSOL,DSOL,RW,IW,IER)

C
C
C      OUTPUT
C
      WRITE (KV,900) HEAD,IER,NYEAR(LT)
900  FORMAT(1H1,10X,'OUTPUT - CASE =',10A4,5X,'IER =',I6,
1  5X,'YEAR =',I6)
      WRITE (KV,903)
903  FORMAT(////35X,'QUANTITY SOLUTION , EXCESS PROFITS & VALUE ',
1  'ADDED BY INDUSTRY')
      VAD=0.0
      QCAP=0.0
      QLAB=0.0
      DO 60 J=1,NM
      QCAP=QCAP+PSOL(J)*AB(15,J)
      QLAB=QLAB+PSOL(J)*AB(16,J)
60  VXP(J)=0.0
      DO 65 I=1,NZ
      J=JZ(I)
65  VXP(J)=Z(I,LT)*DSOL(I+NGD)
      DO 70 J=1,NM
      VA(J)=V(J)*PSOL(J)+VXP(J)
      VAD=VAD+VA(J)
70  WRITE (KV,901) J,(COL(L,J),L=1,5),PSOL(J),VXP(J),VA(J),V(J)
      WRITE (KV,904)
904  FORMAT(////15X,'PRICE SOLUTION',10X,'PP(I)',5X,'DSOL(I)')
      GNP=0.0
      RGNP=0.0
      DO 75 I=1,NGD
      GNP=GNP+DSOL(I)*Y(I)
      RGNP=RGNP+Y(I)
      PP(I)=PK(LT)
      IF(IER.EQ.0) PP(I)=DSOL(I)
      IF(PP(I).LT.PLW) PP(I)=PLW
75  WRITE (KV,902) I,(ROW(L,I),L=1,5),PP(I),DSOL(I)
      PP(15)=PK(LT)
      PP(16)=PL(LT)
      DO 77 I=15,NFACT

```

```

77 WRITE (KV,902) I,(ROW(L,I),L=1,5),PP(I)
902 FORMAT(10X,I3,2X,5A4,2F12.6)
901 FORMAT(10X,I3,2X,5A4,F12.1,5X,F12.1,10X,F12.1,F15.6)
WRITE (KV,905) VAD,GNP,RGNP
905 FORMAT(////10X,'VALUE ADDED =',F12.1,5X,'GNP =',F12.1,
1 5X,'REAL GNP =',F12.1)
WRITE (KV,909) QCAP,QLAB
909 FORMAT(14X,'CAPITAL =',F12.1,5X,'LABOR =',F12.1)
C
C ENERGY BALANCE
C
DO 85 I=1,NFU
EA(I,NMT)=0.0
EB(I,NMT)=0.0
DO 80 J=1,NM
EA(I,J)=AA(I,J)*PSOL(J)/BPFU(I)
EA(I,NMT)=EA(I,NMT)+EA(I,J)
EB(I,J)=AB(I,J)*PSOL(J)/BPFU(I)
80 EB(I,NMT)=EB(I,NMT)+EB(I,J)
EA(I,NMY)=0.0
EB(I,NMY)=Y(I)/BPFU(I)
85 EB(I,NMT)=EB(I,NMT)+EB(I,NMY)
DO 90 J=1,NMT
EA(NFUT,J)=0.0
EB(NFUT,J)=0.0
DO 90 I=1,NFU
EA(NFUT,J)=EA(NFUT,J)+EA(I,J)
90 EB(NFUT,J)=EB(NFUT,J)+EB(I,J)
WRITE (KV,906) HEAD,NYEAR(LT),(I,I=1,NFUT)
906 FORMAT (1H1,5X,'ENERGY SUPPLY - CASE =',10A4,5X,'YEAR =',I6,
1 /25X,11I9)
DO 95 J=1,NMT
95 WRITE (KV,907) J,(COL(L,J),L=1,5),(EA(I,J),I=1,NFUT)
907 FORMAT(I3,2X,5A4,11F9.0)
WRITE (KV,908) (I,I=1,NFUT)
908 FORMAT (////5X,'ENERGY DEMAND',7X,11I9)
DO 100 J=1,NMT
100 WRITE (KV,907) J,(COL(L,J),L=1,5),(EB(I,J),I=1,NFUT)
IF(IER.NE.0) RETURN
GZ(1)=EB(NFUT,NMT)/RGNP
GZ(2)=QCAP/RGNP
GZ(3)=QLAB/RGNP
GZ(4)=GNP/RGNP
WRITE (KW,910) NYEAR(LT),GZ
910 FORMAT(I15,4F15.6)
RETURN
END
SUBROUTINE DEMAND
COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
COMMON /INPT/ AB(16,40),AA(16,40),YA(16),CY,COL(5,40),ROW(5,16),
1 CA(40),HEAD(10),BPFU(10),AIF(16,5,50,15),RN(5),RT(5),RY
COMMON /PRICE/ PK(50),PL(50),TX(40,50),YT(50),PP(16),DD(5,50,50),
1 DF(16,50),Z(40,50)

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COMMON /EQLB/ ANB(16,40),YNA(16)
DIMENSION PI(15),AN(15),PN(5,50),AEF(16,5,50),BPF(5,50),SH(50)
C
DO 60 N=1,NUMN
C
DO 3 M=1,NFACT
3 ANB(M,N+NSUP)=0.0
C
CALCULATE PI - PRICE OF OPTION NI
C
NNL=NUMNN(N)
DO 30 NN=1,NNL
DO 4 M=1,NFACT
4 AEF(M,N,NN)=0.0
NIL=NUMNI(N,NN)
IF(NIL.EQ.1) GO TO 20
SUA=0.0
DO 10 NI=1,NIL
PI(NI)=0.0
DO 5 M=1,NFACT
5 PI(NI)=PI(NI)+AIF(M,N,NN,NI)*PP(M)
AN(NI)=PI(NI)**RN(N)
10 SUA=SUA+AN(NI)
PN(N,NN)=0.0
DO 17 NI=1,NIL
AN(NI)=AN(NI)/SUA
DO 15 M=1,NFACT
15 AEF(M,N,NN)=AEF(M,N,NN)+AN(NI)*AIF(M,N,NN,NI)
17 PN(N,NN)=PN(N,NN)+AN(NI)*PI(NI)
C
GO TO 30
C
20 CONTINUE
PN(N,NN)=0.0
NI=1
DO 25 M=1,NFACT
PN(N,NN)=PN(N,NN)+AIF(M,N,NN,NI)*PP(M)
25 AEF(M,N,NN)=AIF(M,N,NN,NI)
C
30 CONTINUE
RTA=1.0/RT(N)
RTB=RT(N)-1.0
DO 35 NN=1,NNL
IF(LT.EQ.17) BPF(N,NN)=PN(N,NN)
35 CONTINUE
IF(LT.NE.2) GO TO 45
DO 40 NN=1,NNL,10
KB=NN+9
IF(KB.GT.NNL) KB=NNL
WRITE (KW,900) (K,K=NN,KB)
WRITE (KW,901) (PN(N,K),K=NN,KB)
DO 40 M=1,NFACT
40 WRITE (KW,902) M,(AEF(M,N,K),K=NN,KB)
900 FORMAT(////2X,'NN',6X,10I10)

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901 FORMAT (2X,'PN',11X,10F10.6)
902 FORMAT (2X,'AEF M=',I2,5X,10F10.6)

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C

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45 CONTINUE

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C

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      G=0.0
      DO 50 NN=1,NNL
        PN(N,NN)=PN(N,NN)/BPF(N,NN)
        IF(LT.EQ.2) WRITE(KW,905) N,NN,DD(N,NN,LT),PN(N,NN)
905    FORMAT(10X,'N=',I2,5X,'NN=',I3,5X,'DD=',F10.6,5X,'PN=',F10.6)
      50 G=G+DD(N,NN,LT)*(PN(N,NN)**RT(N))
        G=G**RTA
        IF(LT.EQ.2) WRITE (KW,904) N,G
904    FORMAT (10X,'N=',I2,5X,'G=',F10.6)
      DO 55 NN=1,NNL
        AS=DD(N,NN,LT)*((PN(N,NN)/G)**RTB)/BPF(N,NN)
        IF(LT.NE.-1) GO TO 54
        SH(NN)=0.0
        DO 53 M=1,NFU
903    53 SH(NN)=SH(NN)+AEF(M,N,NN)
        SH(NN)=SH(NN)*AS
904    54 CONTINUE
        DO 55 M=1,NFACT
905    55 ANB(M,N+NSUP)=ANB(M,N+NSUP)+AS*AEF(M,N,NN)
        IF (LT.NE.-1) GO TO 60
        XX=0.0
        DO 57 NN=1,NNL
906    57 XX=XX+SH(NN)
        DO 59 NN=1,NNL
          IF(XX.GT.0.0) SH(NN)=SH(NN)/XX
          WRITE(KW,903) N,NN,SH(NN)
907    59 CONTINUE
908    60 CONTINUE
        RETURN
      END
      SUBROUTINE FINAL
      COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)
      1 ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
      COMMON /INPT/ AB(16,40),AA(16,40),YA(16),CY,COL(5,40),ROW(5,16),
      1 CA(40),HEAD(10),BPFU(10),AIF(16,5,50,15),RN(5),RT(5),RY
      COMMON /PRICE/ PK(50),PL(50),TX(40,50),YT(50),PP(16),DD(5,50,50),
      1 DF(16,50),Z(40,50)
      COMMON /EQLB/ ANB(16,40),YNA(16)
      G=0.0
      DO 5 M=1,NGD
        YNA(M)=DF(M,LT)*(PP(M)**RY)
909    5 G=G+YNA(M)
      DO 10 M=1,NGD
910    10 YNA(M)=YNA(M)/G
      RETURN
      END
      SUBROUTINE SUPPLY
      COMMON /BLKN/ NGD,NFACT,NKL,NYR,NSUP,NM,NYEAR(50),NZ,JZ(40)

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1  ,LT,NTYPE,NMT,NMY,NFU,NFUT,NUMN,NUMNN(5),NUMNI(5,50),KW,KV
COMMON /INPT/ AB(16,40),AA(16,40),YA(16),CY,COL(5,40),ROW(5,16),
1 CA(40),HEAD(10),BPFU(10),AIF(16,5,50,15),RN(5),RT(5),RY
COMMON /PRICE/ PK(50),PL(50),TX(40,50),YT(50),PP(16),DD(5,50,50),
1 DF(16,50),Z(40,50)
COMMON /EQLB/ ANB(16,40),YNA(16)
DO 10 M=1,NFACT
DO 10 J=1,NSUP
10 ANB(M,J)=AB(M,J)
RETURN
END
SUBROUTINE TERP (X,NI,NJ,NY,MM)
DIMENSION X(NI,NJ)
DO 20 MI=1,MM
XOLD=X(MI,1)
MOLD=1
DO 15 MJ=2,NY
IF(ABS(X(MI,MJ)).LT.1.0E-12) GO TO 15
MDEL=MJ-MOLD
MSAV=MOLD
IF(MDEL.EQ.1) GO TO 10
DEL=MDEL
DELTA=(X(MI,MJ)-XOLD)/DEL
MDEL=MDEL-1
DO 5 M=1,MDEL
MSAV=MOLD+M
5 X(MI,MSAV)=X(MI,MSAV-1)+DELTA
10 XOLD=X(MI,MSAV+1)
MOLD=MSAV+1
MSAV=MOLD
15 CONTINUE
20 CONTINUE
RETURN
END

```

APPENDIX B

DATA

ELECTRICITY-HIDRO
ELECTRICITY-NUCLEAR
ELECTRICITY-COAL
ELECTRICITY-OIL
ELECTRICITY-GAS
ELECTRICITY-WOOD/WASTE/GEOTH
CRUDE OIL
NATURAL GAS-WELL
NATURAL GAS-TRANSPORTED
NATURAL GAS-DISTRIBUTED
FUEL OIL-LIGHT
FUEL OIL-HEAVY
LIQUIFIED PETROLEUM GAS
COAL
WOOD
SLACK1
SLACK2
SLACK3
SLACK4
SLACK5
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
TRANSPORTATION
IMPORTS
FINAL DEMAND
TOTAL

PROCESSES

ELECTRICITY
CRUDE OIL
NATURAL GAS-WELL
NATURAL GAS-TRANSPORTED
NATURAL GAS-DISTRIBUTED
FUEL OIL-LIGHT
FUEL OIL-HEAVY
LIQUIFIED PETROLEUM GAS
COAL
WOOD
RESIDENTIAL
COMMERCIAL
INDUSTRIAL
TRANSPORTATION
CAPITAL
LABOR

SECTORS

-4.0	-4.0	-6.0	-5.0	-6.0		DEMAND ELASTICITY RN(5)
-1.0	+0.3	+0.3	+0.3	+0.3	+0.3	LOGIT EXP. RY(1),RT(5)
9.61	1.9168	0.774	1.391	2.145	2.923	1.904 BASE FUEL PRICE
2.838	0.9289	1.1				BPFU(10)
0.2	0.2	0.2	0.2	0.2	0.2	0.2 LAG PARAMETER
0.2	0.2	0.2	0.2	0.2	0.2	0.2 CY(1), CA(25)

10668.4	1249.5			1768.6	1755.3	71.8	
			26547.1				AA(N,9)
		12968.1		2601.1	93.0		
					87.2		AB(N,9)
5954.1	2538.8			7377.4	273.5	42.1	
				13884.8			AA(N,10)
			9004.1	1810.5	50.0		
					87.3		AB(N,10)
3206.0	1367.1			1910.9	147.2	22.7	
					65114.5		AA(N,11)
630.8	39990.3		906.3	3420.1	7177.1		
	2.6				19.1	64.8	AB(N,11)
6595.2	3582.9			17577.8	4050.9	2412.4	
						13682.5	AA(N,12)
251.8	15972.6		361.5	4926.5	1508.0		
	1.0				7.6	25.9	AB(N,12)
1385.8	752.8				851.1	506.9	
0.0							AA(N,13)
5660.6							
51.3	3282.2		1973.8		1.6	5.2	AB(N,13)
	0.2				84.3	50.2	
137.2	74.6						AA(N,14)
0.0							
	14191.7			2444.1	17.3		AB(N,14)
338.9					175.4	15.2	
	3.5			3974.8	2375.1	127.9	
4058.0	5584.3						AA(N,15)
0.0							
		2019.2					AB(N,15)
4.3					13.7		
				715.3	415.8	23.5	
353.2	493.4						
1.0	0.0	0.0	0.0	0.0	0.0	0.0	SLACK-1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
500.0	0.0						
0.0	1.0	0.0	0.0	0.0	0.0	0.0	SALCK-2
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
500.0	0.0						
0.0	0.0	0.0	0.0	0.0	0.0	0.0	SALCK-3
0.0	0.0	0.0	0.0	0.0	1.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
500.0	0.0						
0.0	0.0	0.0	0.0	0.0	0.0	0.0	SALCK-4
0.0	0.0	0.0	0.0	0.0	0.0	1.0	

0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
500.0	0.0						
1.0	0.0	0.0	0.0	0.0	0.0	0.0	SALCK-5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0	0.0	0.0	0.0	0.0	0.0	0.0	
500.0	0.0						
0.0							AA(N,21)
			177492.6				
22680.6				10621.6	6318.0		AB(N,21)
1514.1	78.5	596.0		15930.4	12752.8	9.3	
106991.3							AA(N,22)
0.0							
				1466673.3	324.9	1383.2	
16320.2				5475.1	2422.6	1119.6	AB(N,22)
267.1	113.7	11.3		258139.5	114805.9	16556.1	
385175.0	667675.3						AA(N,23)
2871.6							
877.7	8.3			18657.0	1643631.1	114.5	
22905.1	893.2		9685.8		5281.2	9878.2	AB(N,23)
3529.8	3191.8	1409.4		198532.2	733206.2	36545.4	
221908.8	419093.1						AA(N,24)
0.0							
				1334.0	34.2	172546.4	
138.1		418.8			52944.0	1729.8	AB(N,24)
103.6	0.2			18267.9	11385.8	16664.9	
19813.9	52447.6						AA(N,25)
661.2	26892.8			2211.9	3517.4	6129.0	
615.8	79.3			37702.0	103901.6	332.3	
90.2	202.8		85.3		100.4	91.4	AB(N,25)
68.1	1368.3			66491.0	103789.4	9756.4	
0.0	0.0						
1 19.43	12 0.392	13 0.049	14 0.01	15 1.882	16 0.0		ENG-ECON-ENERGY
1 9.91	12 6.302	13 0.784	14 0.016	15 11.058	16 0.0		COEFFICIENTS
5 6.36	12 0.561	13 0.035	14 0.012	15 2.502	16 0.0		AIF(M,N,NN,NI)
5 4.74	12 0.611	13 0.041	14 0.014	15 3.576	16 0.0		RESIDENTIAL
6 10.57	12 0.714	13 0.016	14 0.015	15 1.745	16 0.0		MULT-FAM/NORTH:
8 9.98	12 0.537	13 0.059	14 0.012	15 3.402	16 0.0		SPACE HEAT
8 7.14	12 0.584	13 0.068	14 0.014	15 4.676	16 0.0		
9 8.37	12 0.650	13 0.041	14 0.014	15 8.000	16 0.0		
10 5.43	12 0.611	13 0.041	14 0.014	15 4.784	16 0.0		
1 9.06	12 0.842	13 0.098	14 0.02	15 1.333	16 0.0		WATER HEAT
1 4.24	12 8.109	13 0.922	14 0.184	15 10.823	16 0.0		
5 2.9	12 1.263	13 0.083	14 0.027	15 1.735	16 0.0		
5 2.33	12 1.552	13 0.099	14 0.035	15 2.302	16 0.0		
8 4.09	12 1.208	13 0.137	14 0.028	15 2.735	16 0.0		
8 3.5	12 1.486	13 0.166	14 0.034	15 3.402	16 0.0		
1 1.0	12 0.0	13 0.0	14 0.0	15 1.0	16 0.0		AIR COND.
1 15.42	12 8.030	13 0.91	14 0.19	15 68.9	16 0.0		OTHERS
1 10.72	12 5.850	13 0.66	14 0.14	15 48.1	16 0.0		
5 1.21	12 3.770	13 0.25	14 0.08	15 39.9	16 0.0		
1 10.72	12 5.85	13 0.66	14 0.14	15 48.1	16 0.0		
8 1.84	12 3.61	13 0.41	14 0.08	15 44.7	16 0.0		

1	38.01	12	0.20	13	0.02	14	0.01	15	0.96	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	19.44	12	3.52	13	0.4	14	0.08	15	5.64	16	0.0	
5	13.01	12	0.29	13	0.02	14	0.01	15	1.97	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	9.3	12	0.30	13	0.03	14	0.01	15	2.62	16	0.0	
6	20.74	12	0.36	13	0.01	14	0.01	15	0.89	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	19.58	12	0.27	13	0.03	14	0.01	15	2.97	16	0.0	
8	14.0	12	0.30	13	0.03	14	0.01	15	3.62	16	0.0	SING-FAM/NORTH: SPACE HEAT
9	16.42	12	0.33	13	0.02	14	0.01	15	16.0	16	0.0	
10	10.87	12	0.31	13	0.02	14	0.01	15	8.4	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	17.76	12	0.43	13	0.05	14	0.01	15	0.68	16	0.0	
1	8.33	12	4.14	13	0.46	14	0.1	15	5.52	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	5.69	12	0.64	13	0.04	14	0.02	15	1.63	16	0.0	
5	4.56	12	0.79	13	0.05	14	0.02	15	1.97	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	8.01	12	0.62	13	0.07	14	0.01	15	2.63	16	0.0	
8	6.87	12	0.76	13	0.08	14	0.02	15	2.97	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	
1	15.42	12	8.03	13	0.91	14	0.19	15	68.9	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	10.72	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	
5	1.21	12	3.77	13	0.24	14	0.09	15	39.9	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	10.72	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	
8	1.84	12	3.61	13	0.41	14	0.08	15	44.7	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	7.61	12	0.289	13	0.036	14	0.008	15	4.0	16	0.0	
1	3.91	12	5.101	13	0.579	14	0.116	15	23.565	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	2.46	12	0.414	13	0.026	14	0.009	15	4.0	16	0.0	
5	1.75	12	0.452	13	0.018	14	0.012	15	6.739	16	0.0	SING-FAM/NORTH: SPACE HEAT
6	5.23	12	0.528	13	0.012	14	0.011	15	3.725	16	0.0	
8	3.73	12	0.396	13	0.043	14	0.01	15	5.0	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	2.66	12	0.441	13	0.05	14	0.001	15	7.739	16	0.0	
9	3.46	12	0.481	13	0.018	14	0.012	15	10.00	16	0.0	SING-FAM/NORTH: SPACE HEAT
10	2.73	12	0.452	13	0.018	14	0.012	15	2.652	16	0.0	
1	3.36	12	0.623	13	0.072	14	0.015	15	2.869	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	1.58	12	5.994	13	0.681	14	0.136	15	23.02	16	0.0	
5	1.01	12	0.933	13	0.061	14	0.02	15	2.608	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	0.81	12	1.147	13	0.074	14	0.025	15	4.058	16	0.0	
8	1.24	12	0.098	13	0.123	14	0.025	15	5.058	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	1.54	12	0.892	13	0.061	14	0.021	15	3.608	16	0.0	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	12.4	12	8.03	13	0.91	14	0.19	15	68.9	16	0.0	
1	8.62	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	0.96	12	3.77	13	0.25	14	0.08	15	39.9	16	0.0	
1	8.62	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	1.46	12	3.61	13	0.41	14	0.08	15	44.7	16	0.0	
1	11.03	12	0.20	13	0.02	14	0.01	15	2.76	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	5.67	12	3.52	13	0.4	14	0.08	15	16.26	16	0.0	
5	3.56	12	0.29	13	0.02	14	0.01	15	2.76	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	2.54	12	0.30	13	0.03	14	0.01	15	4.65	16	0.0	
6	7.58	12	0.36	13	0.01	14	0.01	15	2.57	16	0.0	SING-FAM/NORTH: SPACE HEAT
8	5.4	12	0.27	13	0.03	14	0.01	15	3.76	16	0.0	
8	3.86	12	0.30	13	0.03	14	0.01	15	5.65	16	0.0	SING-FAM/NORTH: SPACE HEAT
9	5.02	12	0.33	13	0.02	14	0.01	15	10.0	16	0.0	
10	3.96	12	0.31	13	0.02	14	0.01	15	1.14	16	0.0	SING-FAM/NORTH: SPACE HEAT
1	4.88	12	0.43	13	0.05	14	0.01	15	1.98	16	0.0	
1	2.29	12	4.14	13	0.46	14	0.1	15	15.89	16	0.0	SING-FAM/NORTH: SPACE HEAT
5	1.47	12	0.64	13	0.04	14	0.02	15	1.8	16	0.0	

5	1.18	12	0.79	13	0.05	14	0.02	15	2.8	16	0.0	
8	2.23	12	0.62	13	0.07	14	0.01	15	2.8	16	0.0	
8	1.79	12	0.76	13	0.08	14	0.02	15	3.8	16	0.0	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	AIR COND.
1	12.4	12	8.03	13	0.91	14	0.19	15	68.9	16	0.0	OTHERS
1	8.62	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	
5	0.96	12	3.77	13	0.24	14	0.09	15	39.9	16	0.0	
1	8.62	12	5.85	13	0.66	14	0.14	15	48.1	16	0.0	
8	1.46	12	3.61	13	0.41	14	0.08	15	44.7	16	0.0	
11	1.0	12	0.0	13	0.0	14	0.0	15	0.0	16	0.0	RESIDENTIAL
12	0.0	12	1.0	13	0.0	14	0.0	15	0.0	16	0.0	COMMERCIAL
13	0.0	12	0.0	13	1.0	14	0.0	15	0.0	16	0.0	INDUSTRIAL
14	0.0	12	0.0	13	0.0	14	1.0	15	0.0	16	0.0	TRANSPORTATION
15	0.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	CAPITAL
16	0.0	12	0.0	13	0.0	14	0.0	15	0.0	16	1.0	LABOR
1	13.52	12	0.034	13	0.043	14	0.008	15	2.94	16	0.307	COMMERCIAL
5	6.91	12	0.061	13	0.031	14	0.01	15	2.95	16	0.426	EDUC/HEALTH/HTL:
6	7.9	12	0.108	13	0.014	14	0.014	15	2.73	16	0.511	SPACE HEAT
8	6.85	12	0.041	13	0.051	14	0.01	15	10.0	16	0.426	
10	5.91	12	0.071	13	0.036	14	0.012	15	12.0	16	0.494	
1	6.21	12	0.068	13	0.085	14	0.017	15	2.1	16	0.665	WATER HEAT
5	2.91	12	0.143	13	0.072	14	0.024	15	1.92	16	0.954	
6	3.02	12	0.252	13	0.035	14	0.035	15	1.7	16	1.111	
1	5.73	12	0.184	13	0.23	14	0.046	15	10.98	16	1.87	AIR COND.
5	6.91	12	0.36	13	0.12	14	0.06	15	10.99	16	2.59	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	OTHERS
1	13.52	12	0.036	13	0.045	14	0.009	15	3.234	16	0.307	RETAIL/OFFICE:
5	6.91	12	0.064	13	0.032	14	0.011	15	3.245	16	0.426	SPACE HEAT
6	7.9	12	0.113	13	0.015	14	0.015	15	3.003	16	0.511	
8	6.85	12	0.043	13	0.053	14	0.011	15	10.00	16	0.426	
9	5.91	12	0.075	13	0.037	14	0.013	15	12.00	16	0.494	
1	6.21	12	0.072	13	0.089	14	0.018	15	2.31	16	0.665	WATER HEAT
5	2.91	12	0.15	13	0.076	14	0.025	15	2.112	16	0.954	
6	3.02	12	0.265	13	0.037	14	0.037	15	1.87	16	1.111	
1	5.73	12	0.193	13	0.242	14	0.048	15	12.078	16	1.87	AIR CODN.
5	6.91	12	0.378	13	0.126	14	0.063	15	12.089	16	2.59	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	OTHERS
1	13.52	12	0.032	13	0.041	14	0.007	15	2.646	16	0.276	M/PB/WH/R/AR:
5	6.91	12	0.058	13	0.03	14	0.009	15	2.655	16	0.383	SPACE HEAT
6	7.9	12	0.103	13	0.013	14	0.013	15	2.457	16	0.46	
7	6.85	12	0.039	13	0.048	14	0.009	15	10.00	16	0.383	
9	5.91	12	0.067	13	0.034	14	0.011	15	12.00	16	0.444	
1	6.21	12	0.059	13	0.044	14	0.016	15	1.89	16	0.598	WATER HEAT
5	2.91	12	0.136	13	0.068	14	0.022	15	1.728	16	0.858	
6	3.02	12	0.239	13	0.033	14	0.033	15	1.53	16	0.999	
1	5.73	12	0.175	13	0.218	14	0.043	15	9.882	16	1.683	AIR COND.
5	6.91	12	0.342	13	0.114	14	0.057	15	9.891	16	2.33	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	OTHERS
11	1.0	12	0.0	13	0.0	14	0.0	15	0.0	16	0.0	RESIDENTIAL
12	0.0	12	1.0	13	0.0	14	0.0	15	0.0	16	0.0	COMMERCIAL
13	0.0	12	0.0	13	1.0	14	0.0	15	0.0	16	0.0	INDUSTRIAL
14	0.0	12	0.0	13	0.0	14	1.0	15	0.0	16	0.0	TRANSPORTATION
15	0.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	CAPITAL
16	0.0	12	0.0	13	0.0	14	0.0	15	0.0	16	1.0	LABOR

6	5.0	12	1.2	13	2.4	14	0.4	15	15.0	16	3.5	INDUSTRIAL
8	3.5	12	1.35	13	2.7	14	0.45	15	16.0	16	4.0	AGR/CONT/MIN:(V)
1	8.65	12	0.0082	13	0.0102	14	0.0021	15	0.936	16	0.132	PROCESS HEAT
4	1.85	12	0.0123	13	0.0062	14	0.0021	15	2.16	16	0.132	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	2.16	16	0.132	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	2.16	16	0.132	
1	3.17	12	0.006	13	0.0075	14	0.0015	15	1.24	16	0.025	MECH. DRIVE
4	1.49	12	0.093	13	0.0465	14	0.0155	15	2.48	16	0.155	
6	3.07	12	0.124	13	0.0155	14	0.0155	15	2.48	16	0.155	
8	2.97	12	0.006	13	0.0075	14	0.0015	15	2.48	16	0.155	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	ELECT. SERVICE
4	1.49	12	0.0414	13	0.0207	14	0.0138	15	1.012	16	0.264	FOOD/PAPER/CHEM:
6	3.07	12	0.0552	13	0.0069	14	0.0069	15	1.012	16	0.264	PROCESS STEAM
7	2.01	12	0.0414	13	0.0207	14	0.0138	15	1.012	16	0.264	
8	2.97	12	0.0276	13	0.0345	14	0.0069	15	1.012	16	0.264	
9	0.99	12	0.108	13	0.054	14	0.018	15	3.22	16	0.72	.....
4	2.02	12	0.0432	13	0.0216	14	0.0072	15	2.6036	16	0.528	
6	4.15	12	0.0576	13	0.0072	14	0.0072	15	2.6036	16	0.528	
7	2.71	12	0.0432	13	0.0216	14	0.0072	15	2.6036	16	0.528	
8	4.02	12	0.0288	13	0.036	14	0.0072	15	2.6036	16	0.528	
9	1.88	12	0.1584	13	0.0792	14	0.0264	15	8.28	16	1.44	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.51	16	0.066	PROCESS HEAT
6	2.92	12	0.016	13	0.002	14	0.0021	15	0.51	16	0.066	
7	1.91	12	0.012	13	0.006	14	0.0264	15	0.51	16	0.066	
8	2.83	12	0.008	13	0.01	14	0.002	15	0.51	16	0.066	
9	0.97	12	0.036	13	0.018	14	0.006	15	1.785	16	0.18	.....
1	6.53	12	0.008	13	0.01	14	0.0021	15	0.255	16	0.066	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.51	16	0.066	
6	2.92	12	0.016	13	0.0021	14	0.0021	15	0.51	16	0.066	
8	2.83	12	0.036	13	0.018	14	0.006	15	0.51	16	0.066	.....
4	1.85	12	0.0123	13	0.0061	14	0.0021	15	1.53	16	0.132	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	1.53	16	0.132	
7	2.48	12	0.0122	13	0.0061	14	0.0021	15	1.53	16	0.132	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	1.53	16	0.132	
10	1.26	12	0.0396	13	0.0198	14	0.0066	15	5.406	16	0.258	.....
1	8.65	12	0.0082	13	0.0102	14	0.0021	15	0.663	16	0.132	
4	1.85	12	0.0123	13	0.0061	14	0.0021	15	1.53	16	0.132	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	1.53	16	0.132	
8	3.68	12	0.0083	13	0.0102	14	0.0021	15	1.53	16	0.132	MECH. DRIVE
1	3.17	12	0.0004	13	0.0005	14	0.0001	15	0.1848	16	0.02	
4	1.42	12	0.006	13	0.003	14	0.001	15	0.56	16	0.01	
6	2.92	12	0.008	13	0.001	14	0.001	15	0.56	16	0.01	
7	1.91	12	0.006	13	0.003	14	0.001	15	0.56	16	0.01	
8	2.83	12	0.006	13	0.003	14	0.001	15	0.56	16	0.01	.....
1	3.17	12	0.006	13	0.0075	14	0.0015	15	1.12	16	0.025	
4	1.49	12	0.093	13	0.0465	14	0.0155	15	2.24	16	0.155	
6	3.07	12	0.124	13	0.0155	14	0.0155	15	2.24	16	0.155	
8	2.97	12	0.062	13	0.0775	14	0.0155	15	2.24	16	0.155	
1	9.61	12	0.008	13	0.01	14	0.002	15	2.0	16	0.06	ELECT.SERVICE
1	9.7	12	0.0088	13	0.011	14	0.0022	15	2.8	16	0.072	
4	1.49	12	0.0414	13	0.0207	14	0.0138	15	0.506	16	0.264	STONE/P.METAL:
6	3.07	12	0.0552	13	0.0069	14	0.0069	15	0.506	16	0.264	PROCESS STEAM
7	2.01	12	0.0114	13	0.0207	14	0.0138	15	0.506	16	0.264	
8	2.97	12	0.0276	13	0.0345	14	0.0069	15	0.506	16	0.264	

9	0.99	12	0.108	13	0.054	14	0.018	15	1.61	16	0.72	.....
4	2.02	12	0.0432	13	0.0216	14	0.0072	15	1.3018	16	0.528	
6	4.15	12	0.0576	13	0.0072	14	0.0072	15	1.3018	16	0.528	
7	2.71	12	0.0432	13	0.0216	14	0.0072	15	1.3018	16	0.528	
8	4.02	12	0.0288	13	0.036	14	0.0072	15	1.3018	16	0.528	
9	1.88	12	0.1584	13	0.0792	14	0.0264	15	4.14	16	1.44	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.91	16	0.07	PROCESS HEAT
6	2.92	12	0.016	13	0.002	14	0.0021	15	0.91	16	0.07	
7	1.91	12	0.012	13	0.006	14	0.0264	15	0.91	16	0.07	
8	2.83	12	0.008	13	0.01	14	0.002	15	0.91	16	0.07	
9	0.97	12	0.036	13	0.018	14	0.006	15	3.185	16	0.21	.....
1	6.53	12	0.008	13	0.01	14	0.0021	15	0.455	16	0.07	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.91	16	0.07	
6	2.92	12	0.016	13	0.0021	14	0.0021	15	0.91	16	0.07	
8	2.83	12	0.036	13	0.018	14	0.006	15	0.91	16	0.07	.....
4	1.85	12	0.0123	13	0.0061	14	0.0021	15	2.73	16	0.154	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	2.73	16	0.154	
7	2.48	12	0.0122	13	0.0061	14	0.0021	15	2.73	16	0.154	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	2.73	16	0.154	
9	1.26	12	0.0396	13	0.0198	14	0.0066	15	9.646	16	0.302	.....
1	8.65	12	0.0082	13	0.0102	14	0.0021	15	1.183	16	0.154	
4	1.85	12	0.0123	13	0.0061	14	0.0021	15	2.73	16	0.154	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	2.73	16	0.154	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	2.73	16	0.154	
1	3.17	12	0.0004	13	0.0005	14	0.0001	15	0.2013	16	0.02	MECH. DRIVE
4	1.42	12	0.006	13	0.003	14	0.001	15	0.61	16	0.01	
6	2.92	12	0.008	13	0.001	14	0.001	15	0.61	16	0.01	
7	1.91	12	0.006	13	0.003	14	0.001	15	0.61	16	0.01	
8	2.83	12	0.006	13	0.003	14	0.001	15	0.61	16	0.01	.....
1	3.17	12	0.006	13	0.0075	14	0.0015	15	1.22	16	0.025	
4	1.49	12	0.093	13	0.0465	14	0.0155	15	2.44	16	0.155	
6	3.07	12	0.124	13	0.0155	14	0.0155	15	2.44	16	0.155	
8	2.97	12	0.062	13	0.0775	14	0.0155	15	2.44	16	0.155	
1	9.61	12	0.008	13	0.01	14	0.002	15	2.3	16	0.07	ELECT.SERVICE
1	9.7	12	0.0088	13	0.011	14	0.0022	15	9.2	16	0.084	
4	1.49	12	0.0552	13	0.0276	14	0.0092	15	1.298	16	0.605	MANUF/MISCELL:
6	3.07	12	0.0736	13	0.0092	14	0.0092	15	1.298	16	0.605	PROCESS STEAM
7	2.01	12	0.0552	13	0.0276	14	0.0092	15	1.298	16	0.605	
8	2.97	12	0.0368	13	0.046	14	0.0092	15	1.298	16	0.605	
9	0.99	12	0.144	13	0.072	14	0.024	15	4.13	16	1.65	.....
4	2.02	12	0.0576	13	0.0288	14	0.0096	15	3.3394	16	1.21	
6	4.15	12	0.0768	13	0.0096	14	0.0096	15	3.3394	16	1.21	
7	2.71	12	0.0576	13	0.0096	14	0.0096	15	3.3394	16	1.21	
8	4.02	12	0.0384	13	0.048	14	0.0096	15	3.3394	16	1.21	
9	1.88	12	0.2112	13	0.1056	14	0.0352	15	10.68	16	3.3	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.74	16	0.07	PROCESS HEAT
6	2.92	12	0.016	13	0.002	14	0.0021	15	0.74	16	0.07	
7	1.91	12	0.012	13	0.006	14	0.0264	15	0.74	16	0.07	
8	2.83	12	0.008	13	0.01	14	0.002	15	0.74	16	0.07	
9	0.97	12	0.036	13	0.018	14	0.006	15	2.59	16	0.21	.....
1	6.53	12	0.008	13	0.01	14	0.0021	15	0.37	16	0.07	
4	1.42	12	0.012	13	0.006	14	0.0021	15	0.74	16	0.07	
6	2.92	12	0.016	13	0.0021	14	0.0021	15	0.74	16	0.07	
8	2.83	12	0.036	13	0.018	14	0.006	15	0.74	16	0.07	.....

4	1.85	12	0.0123	13	0.0061	14	0.0021	15	2.22	16	0.154	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	2.22	16	0.154	
7	2.48	12	0.0122	13	0.0061	14	0.0021	15	2.22	16	0.154	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	2.22	16	0.154	
9	1.26	12	0.0396	13	0.0198	14	0.0066	15	7.844	16	0.301	.....
1	8.65	12	0.0082	13	0.0102	14	0.0021	15	0.962	16	0.154	
4	1.85	12	0.0123	13	0.0061	14	0.0021	15	2.22	16	0.154	
6	3.8	12	0.0163	13	0.0021	14	0.0021	15	2.22	16	0.154	
8	3.68	12	0.0082	13	0.0102	14	0.0021	15	2.22	16	0.154	
1	3.17	12	0.0004	13	0.0005	14	0.0001	15	0.2277	16	0.02	MECH.DRIVE
4	1.42	12	0.006	13	0.003	14	0.001	15	0.69	16	0.01	
6	2.92	12	0.008	13	0.001	14	0.001	15	0.69	16	0.01	
7	1.91	12	0.006	13	0.003	14	0.001	15	0.69	16	0.01	
8	2.83	12	0.006	13	0.003	14	0.001	15	0.69	16	0.01	.....
1	3.17	12	0.006	13	0.0075	14	0.0015	15	1.38	16	0.025	
4	1.49	12	0.093	13	0.0465	14	0.0155	15	2.76	16	0.155	
6	3.07	12	0.124	13	0.0155	14	0.0155	15	2.76	16	0.155	
8	2.97	12	0.062	13	0.0775	14	0.0155	15	2.76	16	0.155	
1	9.61	12	0.008	13	0.01	14	0.002	15	1.75	16	0.07	ELECT.SERVICE
1	9.7	12	0.0088	13	0.011	14	0.0022	15	7.0	16	0.084	
11	1.0	12	0.0	13	0.0	14	0.0	15	0.0	16	0.0	RESIDENTIAL
12	0.0	12	1.0	13	0.0	14	0.0	15	0.0	16	0.0	COMMERCIAL
13	0.0	12	0.0	13	1.0	14	0.0	15	0.0	16	0.0	INDUSTRIAL
14	0.0	12	0.0	13	0.0	14	1.0	15	0.0	16	0.0	TRANSPORTATION
15	0.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	CAPITAL
16	0.0	12	0.0	13	0.0	14	0.0	15	0.0	16	1.0	LABOR
6	3.38	12	0.82	13	1.66	14	0.28	15	8.58	16	3.27	TRANSPORTATION
6	2.87	12	0.71	13	1.43	14	0.24	15	7.17	16	2.77	HIGHWAY:
6	1.75	12	0.66	13	1.31	14	0.22	15	6.37	16	2.58	CAR
1	2.85	12	1.96	13	3.8	14	0.58	15	13.49	16	3.9	VAN ELECT.
6	7.29	12	0.7	13	1.4	14	0.43	15	10.69	16	5.57	VAN
6	1.0	12	0.0	13	0.0	14	0.0	15	0.5	16	0.0	BUS INTERCITY
3	0.439	12	1.32	13	0.0	14	0.0	15	1.142	16	0.0	
6	1.0	12	1.0	13	0.0	14	0.0	15	1.0	16	0.0	BUS TRANSIT
6	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	TRUCK
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	RAIL
6	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	
6	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	AIR
6	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	WATER
7	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	
1	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	PIPELINE
6	1.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	MIL. OPER.
11	1.0	12	0.0	13	0.0	14	0.0	15	0.0	16	0.0	RESIDENTIAL
12	0.0	12	1.0	13	0.0	14	0.0	15	0.0	16	0.0	COMMERCIAL
13	0.0	12	0.0	13	1.0	14	0.0	15	0.0	16	0.0	INDUSTRIAL
14	0.0	12	0.0	13	0.0	14	1.0	15	0.0	16	0.0	TRANSPORTATION
15	0.0	12	0.0	13	0.0	14	0.0	15	1.0	16	0.0	CAPITAL
16	0.0	12	0.0	13	0.0	14	0.0	15	0.0	16	1.0	LABOR
11	1.0	12	0.0	13	0.0	14	0.0	15	0.0	16	0.0	IMPORT: RESID.
12	0.0	12	1.0	13	0.0	14	0.0	15	0.0	16	0.0	COMM.
13	0.0	12	0.0	13	1.0	14	0.0	15	0.0	16	0.0	INDUST.
14	0.0	12	0.0	13	0.0	14	1.0	15	0.0	16	0.0	TRANP.
9999												
1	1 1.0	12	1.0	17	1.0	25	1.0	50	1.0	P.CAP.	PK(NYR)	

2	1	1.0	12	1.0	17	1.0	25	1.0	50	1.0	P.LAB. PL(NYR)
3	1	950831	2	1015572	3	1061687	4	1122382	5	1202714	GNP YT(NYR)
3	6	1284879	7	1326408	8	1397269	9	1445850	10	1471614	
3	11	1545588	12	1649215	13	1750963	14	1761180	15	1769103	
3	16	1873172	17	1976563	18	2116637	19	2177169	20	2170369	
3	21	2218893	22	2165544	23	2237206	24	2379625	25	2427530	
3	30	2728000	35	3028000	40	3328000	45	3628000	50	3928000	
-1											
1	1	0.2000	50	0.1090	14	-0.1501	17	0.0001	25	0.1090	TAXES FOR
2	1	0.2001	50	0.1091	14	-0.1502	17	0.0001	25	0.1091	EACH PROCESS
3	1	0.2002	50	0.1092	14	-0.1503	17	0.0002	25	0.1092	AND YEARS 1,
4	1	0.2005	50	0.1095	14	-0.1506	17	0.0005	25	0.1095	14,25,50
5	1	0.2003	50	0.1093	14	-0.1504	17	0.0003	25	0.1093	TX(M,NYR)
6	1	0.2004	50	0.1094	14	-0.1505	17	0.0004	25	0.1094	
7	1	-0.53	50	0.8000	14	-0.0552	17	0.0001	25	0.8000	
8	1	-0.50	50	0.7000	14	-0.4000	17	0.0001	25	0.7000	
9	1	-0.300	50	0.2000	14	-0.2000	17	0.0001	25	0.2000	
10	1	0.1000	50	0.2000	14	-0.030	17	0.0001	25	0.2000	
11	1	0.1700	50	0.3000	14	0.0001	17	0.0001	25	0.3000	
12	1	0.3400	50	0.2000	14	0.1700	17	0.0001	25	0.2000	
13	1	0.4000	50	0.3000	14	0.3000	17	0.0001	25	0.3000	
14	1	-0.47	50	-0.2154	14	-0.0310	17	0.0001	25	-0.2154	
15	1	-0.45	50	-0.2727	14	-0.0455	17	0.0001	25	-0.2727	
16	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
17	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
18	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
19	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
20	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
21	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
22	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
23	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
24	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
25	1	0.0001	50	0.0001	14	0.0001	17	0.0001	25	0.0001	
7	2	-0.5305	3	-0.5305	4	-0.5305	5	-0.5305	6	-0.5305	
7	7	-0.5305	8	-0.5268	9	-0.5352	10	-0.5446	11	-0.5435	
7	12	-0.5670	13	-0.5284	15	-0.0150	16	-0.0286	18	-0.0291	
7	19	0.2683	20	0.8421	21	1.1098	22	0.7467	23	0.5703	
7	24	0.4889									
-1											
1	1	0.00879	14	0.00879	17	0.00879	25	0.00879	50	0.00879	COST SHARE
2	1	0.16120	14	0.16120	17	0.16120	25	0.16120	50	0.16120	COEFFICIENT
3	1	0.19028	14	0.10528	17	0.23028	25	0.16028	50	0.16028	FOR EACH
4	1	0.03431	14	0.03431	17	0.03431	25	0.03431	50	0.03431	ACTIVITY
5	1	0.01386	14	0.01386	17	0.01386	25	0.01386	50	0.01386	WITHIN EACH
6	1	0.00406	14	0.00406	17	0.00406	25	0.00406	50	0.00406	DEMAND PRO-
7	1	0.01425	14	0.00125	17	0.00125	25	0.00125	50	0.00125	CESS & YEAR
8	1	0.06660	14	0.06660	17	0.06660	25	0.06660	50	0.06660	1,14,17,25,
9	1	0.00625	14	0.00625	17	0.00625	25	0.00625	50	0.00625	50
10	1	0.00502	14	0.00502	17	0.00502	25	0.00502	50	0.00502	DD(N,NN,NYR
11	1	0.01510	14	0.00210	17	0.00210	25	0.00210	50	0.00210	RESID.
12	1	0.02856	14	0.02856	17	0.02856	25	0.02856	50	0.02856	
13	1	0.00703	14	0.00703	17	0.00703	25	0.00703	50	0.00703	
14	1	0.00480	14	0.00480	17	0.00480	25	0.00480	50	0.00480	
15	1	0.01602	14	0.00302	17	0.00302	25	0.00302	50	0.00302	

16	1	0.04109	14	0.04109	17	0.04109	25	0.04109	50	0.04109
17	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0
18	1	0.04005	14	0.04005	17	0.04005	25	0.04005	50	0.04005
19	1	0.06796	14	0.06796	17	0.06796	25	0.06796	50	0.06796
20	1	0.00005	14	0.00005	17	0.00005	25	0.00005	50	0.00005
21	1	0.27372	14	0.27372	17	0.27372	25	0.27372	50	0.27372
22	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0
-1										
1	1	0.00420	14	0.00420	17	0.00420	25	0.00420	50	0.00420
2	1	0.00054	14	0.00054	17	0.00054	25	0.00054	50	0.00054
3	1	0.00506	14	0.00506	17	0.00506	25	0.00506	50	0.00506
4	1	0.00306	14	0.00506	17	0.00506	25	0.00506	50	0.00506
5	1	0.00348	14	0.00348	17	0.00348	25	0.00348	50	0.00348
6	1	0.00020	14	0.00020	17	0.00020	25	0.00020	50	0.00020
7	1	0.00486	14	0.00486	17	0.00486	25	0.00486	50	0.00486
8	1	0.00400	14	0.00767	17	0.00767	25	0.00767	50	0.00767
9	1	0.00482	14	0.00482	17	0.00482	25	0.00482	50	0.00482
10	1	0.00012	12	0.00012	17	0.00012	25	0.00012	50	0.00012
11	1	0.00248	14	0.00248	17	0.00248	25	0.00248	50	0.00248
12	1	0.00200	14	0.00365	17	0.00365	25	0.00365	50	0.00365
13	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0
14	1	0.17541	14	0.17541	17	0.17541	25	0.17541	50	0.17541
15	1	0.07805	14	0.07805	17	0.07805	25	0.07805	50	0.07805
16	1	0.01123	14	0.01123	17	0.01123	25	0.01123	50	0.01123
17	1	0.24242	14	0.24242	17	0.24242	25	0.24242	50	0.24242
18	1	0.45075	14	0.45075	17	0.45075	25	0.45075	50	0.45075
-1										
1	1	0.01803	14	0.01803	17	0.01803	25	0.01803	50	0.01803
2	1	0.00070	14	0.00070	17	0.00070	25	0.00070	50	0.00070
3	1	0.00155	14	0.00155	17	0.00155	25	0.00155	50	0.00155
4	1	0.00008	14	0.00006	17	0.00006	25	0.00006	50	0.00006
5	1	0.00233	14	0.00233	17	0.00233	25	0.00233	50	0.00233
6	1	0.00285	14	0.00285	17	0.00285	25	0.00285	50	0.00285
7	1	0.00138	14	0.00138	17	0.00138	25	0.00138	50	0.00138
8	1	0.00035	14	0.00035	17	0.00035	25	0.00035	50	0.00035
9	1	0.00292	14	0.00292	17	0.00292	25	0.00292	50	0.00292
10	1	0.00041	14	0.00041	17	0.00041	25	0.00041	50	0.00041
11	1	0.00060	14	0.00060	17	0.00060	25	0.00060	50	0.00060
12	1	0.00072	14	0.00072	17	0.00072	25	0.00072	50	0.00072
13	1	0.00200	14	0.00390	17	0.00390	25	0.00390	50	0.00390
14	1	0.00112	14	0.00112	17	0.00112	25	0.00112	50	0.00112
15	1	0.00012	14	0.00012	17	0.00012	25	0.00012	50	0.00012
16	1	0.00120	14	0.00120	17	0.00120	25	0.00120	50	0.00120
17	1	0.00107	14	0.00107	17	0.00107	25	0.00107	50	0.00107
18	1	0.00151	14	0.00151	17	0.00151	25	0.00151	50	0.00151
19	1	0.00116	14	0.00116	17	0.00116	25	0.00116	50	0.00116
20	1	0.00008	14	0.00008	17	0.00008	25	0.00008	50	0.00008
21	1	0.00006	14	0.00006	17	0.00006	25	0.00006	50	0.00006
22	1	0.00500	14	0.01299	17	0.01299	25	0.01299	50	0.01299
23	1	0.00052	14	0.00052	17	0.00052	25	0.00052	50	0.00052
24	1	0.00045	14	0.00045	17	0.00045	25	0.00045	50	0.00045
25	1	0.00157	14	0.00157	17	0.00157	25	0.00157	50	0.00157
26	1	0.00045	14	0.00045	17	0.00045	25	0.00045	50	0.00045
27	1	0.00041	14	0.00041	17	0.00041	25	0.00041	50	0.00041

COMM.

INDUST.

28	1	0.00037	14	0.00037	17	0.00037	25	0.00037	50	0.00037	
29	1	0.00007	14	0.00007	17	0.00007	25	0.00007	50	0.00007	
30	1	0.00006	14	0.00006	17	0.00006	25	0.00006	50	0.00006	
31	1	0.00075	14	0.00055	17	0.00055	25	0.00055	50	0.00055	
32	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0	
33	1	0.11838	14	0.11838	17	0.11838	25	0.11838	50	0.11838	
34	1	0.43943	14	0.43943	17	0.43943	25	0.43943	50	0.43943	
35	1	0.02169	14	0.02169	17	0.02169	25	0.02169	50	0.02169	
36	1	0.11288	14	0.11288	17	0.11288	25	0.11288	50	0.11288	
37	1	0.24806	14	0.24806	17	0.24806	25	0.24806	50	0.24806	
-1											
1	1	0.35000	14	0.35000	17	0.35000	25	0.35000	50	0.35000	TRANP.
2	1	0.02419	14	0.02419	17	0.02419	25	0.02419	50	0.02419	
3	1	0.30740	14	0.30740	17	0.30740	25	0.30740	50	0.30740	
4	1	0.00027	14	0.00027	17	0.00027	25	0.00027	50	0.00027	
5	1	0.04754	14	0.04754	17	0.04754	25	0.04754	50	0.04754	
6	1	0.00081	14	0.00081	17	0.00081	25	0.00081	50	0.00081	
7	1	0.00643	14	0.00643	17	0.00643	25	0.00643	50	0.00643	
8	1	0.01283	14	0.01283	17	0.01283	25	0.01283	50	0.01283	
9	1	0.00857	14	0.00857	17	0.00857	25	0.00857	50	0.00857	
10	1	0.00544	14	0.00544	17	0.00544	25	0.00544	50	0.00544	
11	1	0.00160	14	0.00160	17	0.00160	25	0.00160	50	0.00160	
12	1	0.00642	14	0.00642	17	0.00642	25	0.00642	50	0.00642	
13	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0	
14	1	0.08648	14	0.08648	17	0.08648	25	0.08648	50	0.08648	
15	1	0.02872	14	0.02872	17	0.02872	25	0.02872	50	0.02872	
16	1	0.08970	14	0.08970	17	0.08970	25	0.08970	50	0.08970	
17	1	0.01180	14	0.01180	17	0.01180	25	0.01180	50	0.01180	
18	1	0.01180	14	0.01180	17	0.01180	25	0.01180	50	0.01180	
-1											
1	1	0.0	14	0.0	17	0.0	25	0.0	50	0.0	IMPORT
2	1	0.37553	14	0.37553	17	0.37553	25	0.37553	50	0.37553	
3	1	0.57088	14	0.57088	17	0.57088	25	0.57088	50	0.57088	
4	1	0.05359	14	0.05359	17	0.05359	25	0.05359	50	0.05359	
-1											
11	1	0.0898	14	0.0898	17	0.0898	25	0.0898	50	0.0898	SHARE COEFF
12	1	0.47934	14	0.47934	17	0.47934	25	0.47934	50	0.47934	FOR TOTAL
13	1	0.38579	14	0.38579	17	0.38579	25	0.38579	50	0.38579	DEMAND SECT
14	1	0.04507	14	0.04507	17	0.04507	25	0.02507	50	0.02507	DF(...,NYR)
-1											
1	1	4946.7	2	5389.9	3	5124.8	4	5290.9	5	5629.8	BOUNDS FOR
1	6	5374.7	7	5931.2	8	5616.8	9	6107.9	10	5983.2	PROCESS #
1	11	6597.4	12	6893.8	13	6136.5	14	9687.5	15	9699.8	Z(...,NYR)
1	16	9215.6	17	7232.6	18	9731.5	19	9686.9	20	10370.4	ELECT-HIDR
1	21	10344.5	22	12967.9	23	13743.6	24	13471.9	25	11967.1	
1	50	21000.0									
2	1	55.0	2	72.7	3	99.3	4	99.8	5	106.9	ELECT-NUCL
2	6	152.4	7	204.9	8	319.1	9	340.0	10	527.0	
2	11	943.9	12	1367.8	13	1882.6	14	3661.1	15	5576.3	
2	16	6207.0	17	8231.3	18	9591.5	19	8834.1	20	9434.3	
2	21	10820.3	22	11859.0	23	12145.4	24	13742.3	25	16331.8	
2	50	33000.0									
3	1	13882.1	2	14567.2	3	15426.2	4	15883.0	5	16748.7	ELECT-COAL
3	6	17101.5	7	17052.2	8	17624.2	9	17410.0	10	17245.6	

3	11	17885.9	12	19741.4	13	19298.8	14	26984.9	15	27852.5	
3	16	30990.0	17	32640.8	18	34234.2	19	37616.7	20	44095.9	
3	21	48243.5	22	50513.4	23	52614.6	24	56852.5	25	60285.9	
3	50	75000.0									
4	1	6454.1	2	6898.9	3	7284.9	4	7683.9	5	7519.9	ELECT-GAS
4	6	8100.2	7	8286.4	8	9064.3	9	9508.9	10	10536.9	
4	11	10828.9	12	11104.1	13	8988.5	14	12036.6	15	11325.0	
4	16	11183.1	17	11705.2	18	12385.7	19	13332.0	20	15201.9	
4	21	16036.1	22	14962.0	23	13248.6	24	14580.1	25	14523.1	
4	50	25000.0									
5	1	0.001	2	0.001	3	0.001	4	0.001	5	0.001	ELECT-W/W/G
5	6	0.01	7	0.01	8	0.1	9	0.1	10	24.2	
5	11	24.7	12	50.6	13	45.2	14	96.5	15	97.0	
5	16	129.9	17	133.2	18	104.1	19	138.4	20	225.4	
5	21	238.1	22	209.7	23	248.1	24	251.7	25	255.4	
5	50	400.0									
6	1	58510.7	2	64862.1	3	67075.6	4	70633.9	5	78096.8	IMPORT
6	6	88814.8	7	94332.5	8	108263.5	9	115886.8	10	119732.0	
6	11	122730.6	12	136746.6	13	151678.0	14	163976.5	15	144268.5	
6	16	171342.4	17	182043.3	18	207107.2	19	222648.3	20	218891.9	
6	21	227214.7	22	221809.4	23	243155.9	24	300565.4	25	307778.1	
6	50	600000.0									
7	1	40000.0	2	40000.0	3	40000.0	4	40000.0	5	40000.0	ELEC-OIL
7	6	40000.0	7	40000.0	8	40000.0	9	40000.0	10	40000.0	
7	11	40000.0	12	40000.0	13	13500.0	14	40000.0	15	40000.0	
7	16	20000.0	17	20000.0	18	20000.0	19	20000.0	20	20000.0	
7	21	20000.0	22	20000.0	23	20000.0	24	20000.0	25	20000.0	
7	50	30000.0									
8	1	80462.0	2	80144.0	3	80134.0	4	80552.0	5	80344.0	CRUDE-OIL
8	6	80632.0	7	80030.0	8	80482.0	9	80032.0	10	80880.0	
8	11	80066.0	12	80088.0	13	80878.0	14	80854.0	15	80006.0	
8	16	80972.0	17	38390.0	18	40546.0	19	39820.0	20	40150.0	
8	21	39930.0	22	40282.0	23	40304.0	24	40000.0	25	40000.0	
8	50	70000.0									

IMSL SUBROUTINE ZX4LP

PURPOSE Solve the linear programming problem via the
 Revised Simplex Algorithm

USAGE CALL ZX4LP(XA,IA,XB,XC,NM,NN,NE,SS,PSOL,DSOL,RW,
 IW,IER)

ARGUMENTS XA Matrix of dimension $NN+NE+2$ by $NM+NN+2$ containing the coefficients of the NN inequality constraints in the first NN rows followed by the coef. of the NE equality constraints.
The last two rows and the last $NN+2$ columns of XA are used only as working storage. (Input)

IA Row dimension of matrix XA exactly as specified in the dimension statement in the calling program. IA must be at least $NN+NE+2$. (Input)

XB Vector of length $NN+NE+2$ containing the right hand sides of the inequality constraints in its first NN locations followed by the NE right hand sides of the equality constraints. (Input)

XC Vector of length NM containing the coefficients

of the objective function.	(Input)	155
NM Number of unknowns in the model.	(Input)	
NN Number of inequality constraints.	(Input)	
NE Number of equality constraints.	(Input)	
SS Value of the objective function.	(Output)	
PSOL Vector of length NM containing the primal solution.	(Output)	
DSOL Vector of length NN+NE containing the dual solution.	(Output)	
RW Real work vector.		
IW Integer work vector.		
IER Error parameter.	(Output)	
Terminal errors:129,130,131,132,132,134,135,136		

LINEAR PROGRAMMING PROPERTIES AND INTERPRETATION

The linear programming (LP) problem is to satisfy final demands at the least total cost. To pose the LP problem we define a net output vector, D_{ij} , and a total cost, T , by

$$D_{ij} = A_{ij} - B_{ij}$$

$$T = \sum_j V_j X_j$$

The primal problem is

$$\text{Minimize } T = \sum_j V_j X_j$$

subject to

$$\sum_j X_j D_{ij} \geq Y_i \quad i = 1, N$$

$$0 \leq X_j \leq Z_j \quad j = 1, M$$

Every LP problem has a dual problem, for our LP problem, the dual is

$$\text{Maximize } R = \sum_i P_i Y_i - \sum_j \pi_j Z_j$$

subject to

$$\sum_i P_i D_{ij} \leq V_j + \pi_j$$

At optimality, $T = R$ and the dual variables P_i and π_j are obtained as:

$$[T]_{Y_i} = P_i \quad \text{Marginal cost of producing good or service } i$$

$$[T]_{Z_j} = -\pi_j \quad \text{Excess of profit for process } j$$

The variables in the primal problem and the dual problem satisfy the following relationships

$$(Z_j - X_j) \pi_j = 0$$

$$(\sum_j X_j D_{ij} - Y_i) P_i = 0$$

$$(V_j + \pi_j - \sum_i P_i D_{ij}) X_j = 0$$

The GNP is the total value of the final demand, and at optimality

$$\text{GNP} = \sum_i P_i Y_i = \sum_j (V_j + \pi_j) X_j$$

A summary of LP properties is presented next:

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PRIMAL	DUAL
Minimize $T = \sum V_j X_j$ such that $\sum X_j D_{ij} \geq Y_i$ $0 \leq X_j \leq Z_j$ $i=1, N \quad j=1, M$	Maximize $R = \sum P_i Y_i - \sum \pi_j Z_j$ such that $\sum P_i D_{ij} \leq V_j + \pi_j$ $P_i, \pi_j \geq 0$ $i=1, N \quad j=1, M$

INTERPRETATION OF THE DUAL VARIABLES (AT OPTIMUM $T=R$)

[T] $Y_i = P_i$ Marginal cost of producing fuel i (Marginal price)

[T] $Z_j = -\pi_j$ Marginal reduction in cost if constraint j is relaxed (Marginal excess profit)

INTERPRETATION OF SLACKNESS-CONSTRAINT CONDITIONS			
CONSTRAINT	CONDITION	IF	THEN
Boundary		Process is not at full capacity	Excess of profit are zero
$Z_j - X_j \geq 0$	$(Z_j - X_j) \pi_j = 0$	$Z_j > X_j$	$\pi_j = 0$
		Excess of profit are positive	Industry at full capacity
		$\sum \pi_j > 0$	$Z_j = X_j$
Primal		Economy produces an exc. amt. fuel	The price of the fuel is zero
$\sum X_j D_{ij} - Y_i \geq 0$	$(\sum X_j D_{ij} - Y_i) P_i = 0$	$\sum X_j D_{ij} > Y_i$	$P_i = 0$
		Price-fuel or serv. is positive	Suppl. must equal demand for i
		$P_i > 0$	$\sum X_j D_{ij} = Y_i$
Dual		Cost operating Proc. j GT Income	Process will not be operated
$V_j + \pi_j - \sum P_i D_{ij} \geq 0$	$(V_j + \pi_j - \sum P_i D_{ij}) X_j = 0$	$V_j + \pi_j > \sum P_i D_{ij}$	$X_j = 0$
		There is an out put from proc. j	Income equal to cost oper. + exc.
		$X_j > 0$	$\sum P_i D_{ij} = V_j + \pi_j$

INTERPRETATION OF GNP AT OPTIMALITY ($R=T$)

$$\sum P_i Y_i - \sum \pi_j Z_j = \sum V_j X_j$$

$$GNP = \sum (V_j X_j + \pi_j Z_j)$$

If Processes are at full capacity $Z_j = X_j$

$$GNP = \sum (V_j + \pi_j) X_j$$

EXAMPLE: PETROLEUM REFINING SECTOR

(Example of structuring the new I-O table)

Similar procedures apply for the other sectors

Definition: The Petroleum Refining sector can be defined as
 in the Glossary of the Annual Report to Congress
 [66] and according to the following aggregation

Light fuel oil (FO/L) : Distillate fuel

Kerosene

Motor gasoline

Aviation gasoline

Jet fuel

Heavy fuel oil (FO/H) : Residual fuel

Liquid Petroleum Gas (LPG) : LPG

Ethane

Total commodity output	100,031.7 10^6 [\$]
Self consumption	6,105.6 10^6 [\$]
Net commodity trade	93,926.1 10^6 [\$]

These quantities are taken from Appendix L Table A and
 are the basic control totals.

In what follows, energy quantities of refined petroleum
 consumed or produced by the different demand or supply in-
 dustries, and the average fuel price for the sector, will
 allow us to obtain the USE and MAKE real energy transactions
 values for the three disaggregated sectors FO/L, FO/L & LPG.

	FO/L	FO/H	LPG	TOTAL
Residential	2,161.1		533.5	2,695.0
Commercial	828.8	588.0	94.1	1,510.9
Transportation	18,112.9	908.5	36.5	19,057.9
Industrial	2,058.9	5,246.5	1,234.8	8,549.2
Electric Utility	283.5	3,614.2		3,897.7
Export	34.0	48.0	24.0	106.0
TOTAL	23,479.6	10,405.2	1,931.9	35,816.7
Import	1,203.0	3,219.0	217.0	4,639.7

The above quantities were obtained for the Residential, Commercial, Industrial, Transportation and Electric Utility sectors from [64] pg. 16,17,18,19,20.; and for Import and Export from [67] pg. 83,87,243.

Assumptions were made for data on lubricants, wax and asphalt as well as for feedstock.

Average price for the fuel sector:

$$(93,926.1)/(35,817.6) = 2.622 \text{ [}/10^6\text{BTU]}$$

Average price for FO/L,FO/H,LPG:

$$P_L Q_L + P_H Q_H + P_G Q_G = \text{Net commodity trade}$$

$$P_L(23,479.6) + P_H(10,405.2) + P_G(1,931.9) = 93,926.1$$

Wholesale price data from [66] pg.65, [67] pg.133., gives

$$(2) \quad P_G = 2.838 \text{ [}/10^6\text{BTU}] \text{ and } P_H = 1.904 \text{ [}/10^6\text{BTU}]$$

$$\text{then } P_L = 2.923 \text{ [}/10^6\text{BTU}] \text{ (Consistency of prices)}$$

(3) Energy into Crude Oil and Nat.Gas: [58] pg.5-4,5-5. 160

	Quantity	Convers. Fact.	10^{12} [BTU]
Distilled oil	15,469.4 10^3 [BBL]	5.825 [10^6 BTU/BBL]	90.11
Natural gas	218.0 10^9 [CF]	1.019 [BTU/CF]	222.10
Motor gasoline	233.4 10^6 [Gal]	5.253 [10^6 BTU/BBL]	27.94
Electricity	19.6 10^9 [KWH]	3.412 [BTU/KWH]	67.14
TOTAL			407.29

Input from Petroleum Refining into Crude Oil and Nat.Gas:

$$90.11 + 27.94 = 118.1 \text{ } 10^6 \text{[BTU]}$$

Share of FO/L into CO and NG/W : [67] pg.5.

	10^{15} [BTU]	Share	x 118.1
CO	17.45	0.4435	52.4
NG/W	21.90	0.5565	65.7
TOTAL	39.35		

where : NG/W is defined as Nat. Gas Dry-well and
Nat. Gas Plant Lease

(4) Energy into Coal: [58] pg.5-4,5-5.

	Quantity	Conv. Fact.	10^{12} [BTU]
Distilled oil	8.940 10^3 [BBL]	5.825	52.08
Residual oil	1.268 10^3 [BBL]	6.287	7.97
Coal	173.7 10^3 [ST]	22.482 [10^6 BTU/ST]	3.9
Gas	1.7 10^9 [CF]	1.019	1.94
Motor gasoline	63.3 10^6 [Gal]	5.235	7.92
Electricity	10.335 10^9 [KWH]	3.412	35.26
TOTAL			109.07

Input from Petroleum Refining into Coal

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$$\text{FO/L} : 52.08 + 7.92 = 60 \cdot 10^6 [\text{BTU}]$$

$$\text{FO/H} : 7.97 \cdot 10^6 [\text{BTU}]$$

(5) Energy into Gas Production and Distribution:

Energy information is not available, so we use data from I-O table and assume all inputs come from light fuel oil

$$\text{FO/L} : 175.4 \cdot 10^6 [\$]$$

Share of FO/L into NG/T and NG/D: [50]

	Share	x 174.5 10^6 [\$]
NG/T	0.5	87.2
NG/D	0.5	87.3

(6) Energy into Petroleum Refining: [57] pg.4-20,4-21.

	Quantity	Fact. Conv.	10^{12} [BTU]
Distilled oil	$1.6644 \cdot 10^3$ [BBL]	5.825	9.70
Residual oil	$8.0108 \cdot 10^3$ [BBL]	6.287	50.36
Coal	$0.1836 \cdot 10^3$ [ST]	22.29	4.09
Nat. Gas	$1,016.4 \cdot 10^9$ [CF]	1.019	1,035.71
Electricity	$28.4824 \cdot 10^9$ [KWH]	3.412	97.18
TOTAL			1,197.04

FO/L : $9.7 \cdot 10^{12}$ [BTU]

FO/H : $50.4 \cdot 10^{12}$ [BTU]

Share of FO/L and FO/H into FO/L, FO/H, LPG: [64] pg.14

	10^{12} [BTU]	Share	x 9.7	x 50.4
Motor gasoline	13,760.4			
Jet fuel	2,126.5			
Distilled oil	7,125.9			
Kerosene	362.7			
Aviation gasol.	70.3			
FO/L	23,445.8	0.6754	6.5	34.0
Residual oil	7,047.3			
Others	2,312.9			
FO/H	9,360.2	0.2696	2.6	13.6
LPG	1,907.9	0.0550	0.5	2.8
TOTAL	34,713.9			

Considering energy inputs (1),(3),(4),(5),(6), average prices (2) and the fact that all energy consumed or produced by the energy industries should come from the industrial sector, we can calculate the following USE and MAKE tables for FO/L, FO/H and LPG sectors:

USE (10^6 [\$])	FO/L	FO/H	LPG
E	828.7	6,881.4	
CO	153.0		
NG/W	192.1		
NG/T	87.2		
NG/D	87.3		
FO/L	19.1	64.8	
FO/H	7.6	25.9	
LPG	1.6	5.2	
C	175.4	15.2	
W	13.7		
Residential	6,318.0		1,514.1
Commercial	2,422.6	1,119.6	267.1
Industrial	5,281.2	9,878.2	3,529.8
Transport.	52,944.0	1,729.8	103.6
Exports	100.4	91.4	68.1
TOTAL	68,631.9	19,811.5	5,482.7

MAKE (10^6 [\$])	FO/L	FO/H	LPG
NG/W			2,632.9
FO/L	65,114.5		
FO/H		13,682.5	
LPG			1,356.3
Industrial			877.7
Imports	3,517.4	6,129.0	615.8
TOTAL	68,631.9	19,811.5	5,482.7

Electricity : [59] pg. 14,15,18,19,22,31,43.

[55] pg. 89.

[61] pg. 79.

[58] pg. 5-5,4-21.

Crude Petroleum and Nat.Gas: [64] pg. 16,17,18,19,20.

[67] pg. 5,29,87,93,145,248.

[66] pg. 13,61

[58] pg. 5-4,5-5.

Gas Production and Distribution : [64] pg. 16,17,18,19,20.

[67] pg.5,9,87,93,145,248.

[66] pg. 13,61.

[60] pg. 60,114,118.

[69] pg. 58,59.

Coal : [64] pg. 16,17,18,19,20.

[67] pg. 165,175,246,247.

[57] pg. 4-14.

[58] pg. 5-15.

Wood : [71] pg. 95.

[65] pg. 7.

[57] V1. , V2 Part 1.

THE REVENUE REQUIREMENT METHOD (Summary of [73])

The Revenue Requirement Method (RR) is also called the "minimum revenue requirement method" because it describes the minimum revenue that can cover all costs, including a minimum acceptable return on capital investment. This method assumes that the cost of money is known and that the revenue stream R_i and/or its present worth is to be determined.

The minimum revenue requirement R_i in the year i should be enough to cover all costs, which includes operating costs, ad valorem charges, recovery of capital (through depreciation charge), return on the outstanding capital tied up and income taxes.

$$R_i = O_i + \pi_i + D_i^B + rV_i + T_i ,$$

where $r = r_b f_b + r_s(1-f_b)$

All elements are defined at the end of the appendix.

The purpose of the RR formulation is to collapse R_i into one value that can represent the attractiveness of the project. The present worth revenue requirement (PWRR) is a convenient value obtained by computing the present value, for each year i , of the right-hand side of R_i and then adding the results for all years. Any discount rate can be used in the present value calculation without disturbing the definitional nature of R_i , provided that the PWRR is qualified by that discount rate.

R_i can be written as:

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$$\Sigma R_i / (1+x)^i = \Sigma (O_i + \pi_i) / (1+x)^i + [1/(1-\tau)] \Sigma I_i / (1+x)^i - (\tau/(1-\tau)) \Sigma D_i^T / (1+x)^i$$

where $x = r - \tau r_b f_b$

when $i=0$, some quantities, namely T_i , π_i , D_i are zero.

Similar to the Discount Cash Flow (DCF) formulation, there are special cases of the RR formulation:

1. Present Worth of Revenue Required to Cover Costs Associated with Capital.

The last equation has two components: revenues to cover operating costs (fuels and operations and maintenance), and revenues to cover costs associated with capital. It can be written as functions of :

$$PWRR_x = PWRRO_x(O_i) + PWRI_x(I_i, D_i^T, \pi_i)$$

where $PWRI_x = I_0 Z_I$

$$Z_I = 1/(1-\tau) - [\tau/(1-\tau)] [d^*/CRF(x, M) + \pi/CRF(x, M)]$$

$$CRF(x, M) = x/[1-(1+x)^{-M}]$$

$$d^* = CRF(x, M) \Sigma d_i / (1+x)^i$$

2. Levelized Annual Capital Charge Rate.

$PWRI_x$ can further be written as:

$$PWRI_x = \Sigma I_0 \phi / (1+x)^i = I_0 \phi / CRF(x, M)$$

where $\phi = CRF(x, M)/(1-\tau) - [\tau/(1-\tau)] d^* + \pi$

- R Gross annual revenue (dollars)
- O Operating cost (fuel, operation and maintenance)
- π Ad-valorem charges
- D Depreciation charges
- D^B Book depreciation charges
- D^T Tax depreciation charges
- V Unrecovered value of the investment
- T Income tax
- r Nominal after-tax rate of return on capital
- r_b Required rate of return on bond (int. rate of debt)
- f_b Fraction of capital that is bond (debt)
- r_s Minimum required rate of return to stock (equity)
- f_s Fraction of capital that is stock (equity)
- I Capital investment
- x Effective after-tax rate of return
- τ Effective income tax rate
- $PWRR_x$ Present worth of revenue requirement (x disc.rate)
- Z_I Present worth factor to be multiplied with the beginning-of-life investment to obtain $PWRRI_x$
- d Depreciation rate
- d^* Levelized depreciation charge rate
- $CRF(x,M)$ Capital recovery factor of rate x in periods M
- ϕ Levelized annual capital charge rate (fixed charge rate).

APPENDIX G

EXAMPLE: SINGLE-FAMILY UNIT IN THE SOUTH
 (Example of calculating the engineering-economic-energy coefficient)
 Similar procedure apply for the other demand processes.

Knowing the demand of energy for each activity during a period of time (yr. 1977), and given the efficiency of the related equipment and prices of fuel on base year; the specific energy cost can be calculated.

Knowing the operating or maintenance cost, over a period of time, and given the proportion for material and labor; the specific material and labor cost can be calculated.

Knowing the investment cost, and given the life cycle, income tax rate, bonds and stocks (if required); the leveled cost can be calculated.

ACTIVITY	DEMAND	EFFICIENCY		ENERGY	COST	OPERATING	COST	CAPITAL	COST
		ABS.	REL.	*		MAT.	LAB.	INVT.	LEVZ.**
	10 ⁶ [BTU/YR]			\$/[10 ⁶ BTU]		\$/[10 ⁶ BTU]		\$/[10 ⁶ BTU]	
SPACE HEAT									
Elec. resistance	32.4	.95	1.05	11.03	.05	.18	17.2	2.76	
Elec. heat pump	32.4	1.85	.54	5.67	.8	3.2	101.0	16.26	
L.eff.NG/D furnace	32.4	.5	2.0	3.56	.06	.25	17.4	2.76	
H.eff.NG/D furnace	32.4	.7	1.43	2.54	.07	.27	28.9	4.65	
L.eff.LPG furnace	32.4	.5	2.0	5.4	.06	.25	17.4	2.76	
H.eff.LPG furnace	32.4	.7	1.43	3.8	.07	.27	28.9	4.65	
Oil furnace	32.4	.52	1.92	7.58	.08	.3	16.0	2.57	
Coal furnace	32.4	.5	2.0	5.02	.07	.29	15.4	2.48	
Wood stove(E.back)	32.4		1.89	3.96	.07	.27	7.1	1.14	
WATER HEAT									
Elec. resistance	12.4	.78	1.28	4.88	.1	.39	12.3	1.98	
Elec. heat pump	12.4	1.65	.6	2.29	.94	3.76	98.7	15.89	
L.eff.NG/D furnace	12.4	.44	2.27	1.47	.14	.56	11.2	1.8	
H.eff.NG/D furnace	12.4	.55	1.82	1.18	.17	.69	17.4	2.8	
L.eff.LPG furnace	12.4	.44	2.27	2.23	.14	.56	11.2	1.8	
H.eff.LPG furnace	12.4	.55	1.82	1.79	.17	.69	17.4	2.8	
AIR CONDITIONING									
Elec. central	32.4	2.2	.45	4.73	.27	1.06	64.1	10.32	
Elec. window	13.0	2.16	.46	4.83	.44	1.76	65.4	10.52	
OTHERS									
OPTION: E				12.4	1.83	7.3		68.9	
Refrigerator	3.7	.95	1.05		1.35		108.1		
Range	4.6	.95	1.05		1.08		86.9		
Dish washer	4.5	.95	1.05		2.22		77.7		
Clothes washer	4.2	.95	1.05		2.38		83.3		
Clothes dryer	7.1	.95	1.05		1.4		42.3		
Light and rest	14.3	.95	1.05		.7		30.0		
OPTION:E&NG/D; E		.86		8.62	1.33	5.32	48.1		
NG/D				.96	.82	3.28	39.9		
Refrigerator	3.7	.95	1.05		1.35		108.1		
Range	2.8	1.58	.86		1.78		178.5		
Dish washer	4.5	.95	1.05		2.22		77.7		
Clothes washer	4.2	.95	1.05		2.38		83.3		
Clothes dryer	4.3	1.58	.86		2.32		69.7		
Light and rest	14.3	.95	1.05		.7		30.0		
OPTION:E&LPG ; E		.86		8.62	1.33	5.32	48.1		
LPG				1.46	.82	3.28	44.72		
Refrigerator	3.7	.95	1.05		1.35		108.1		
Range	2.8	1.58	.86		1.78		196.4		
Dish washer	4.5	.95	1.05		2.22		77.7		
Clothes washer	4.2	.95	1.05		2.38		83.3		
Clothes dryer	4.3	1.58	1.05		2.32		81.4		
Light and rest	14.3	.95	.86		.7		30.0		

* (Relative efficiency)(Base energy unit factor)(Fuel base price)

where: Relative efficiency = $1/(\text{Absolute efficiency})$

Base energy unit factor = $(\text{Activity year demand})/32.4$

Fuel base prices as in Appendix L, Table B

** From Appendix F : For M=20 Life cycle
 $\tau=.5$ Effective income tax rate
 $rb=.08$ Rate of return on bond (debt)
 $fb=.5$ Fraction of capital is bond (debt)
 $rs=.13$ Rate of return to stock (equity)
 $fs=.5$ Fraction of capital is stock (equity)
 Get $x=.085$ Effective after tax of return
 $CRF=.1056$ Capital recovery factor
 $d=.05$ Levelized depreciation charge rate
 $\phi=.161$ Levelized annual capital charge rate
 Then
 $(\text{INVT})\phi=\text{LEVZ}$ Levelized annual capital investment

Assuming that the Material coefficient can be broken down into Commercial, Industrial and Transportation coefficients in proportions as stated in section 6.2.1 we can finally obtain the AIF coefficients.

When there is no fuel option, we set equal unit coefficients for Energy and Capital. In this sector, the Labor coefficient is considered as a service and is added to the Commercial coefficient.

ENERGY	COMMERCIAL	INDUSTRIAL	TRANSPORTATION	CAPITAL	LABOR	AIF(M,N,NN,NI)
SPACE HEAT						
11.03	.20	.02	.01	2.76	0.0	AIF(1,1,13, 1)
5.67	3.52	.4	.08	16.26	0.0	AIF(1,1,13, 2)
3.56	.29	.02	.01	2.76	0.0	AIF(5,1,13, 3)
2.54	.30	.03	.01	4.65	0.0	AIF(5,1,13, 4)
7.58	.36	.01	.01	2.57	0.0	AIF(6,1,13, 5)
5.4	.27	.03	.01	2.76	0.0	AIF(8,1,13, 6)
3.86	.30	.03	.01	4.65	0.0	AIF(8,1,13, 7)
5.02	.33	.02	.01	2.48	0.0	AIF(9,1,13, 8)
3.96	.31	.02	.01	1.14	0.0	AIF(10,1,13, 9)
WATER HEAT						
4.88	.43	.05	.01	1.98	0.0	AIF(1,1,14, 1)
2.29	4.14	.46	.1	15.89	0.0	AIF(1,1,14, 2)
1.47	.64	.04	.02	1.8	0.0	AIF(5,1,14, 3)
1.18	.79	.05	.02	2.8	0.0	AIF(5,1,14, 4)
2.23	.62	.07	.01	1.8	0.0	AIF(8,1,14, 5)
1.79	.76	.08	.02	2.8	0.0	AIF(8,1,14, 6)
AIR CONDITIONING						
1.0	0.0	0.0	0.0	1.0	0.0	AIF(1,1,15, 1)
OTHERS						
12.4	8.03	.91	.19	68.9	0.0	AIF(1,1,16, 1)
8.62	5.85	.66	.14	48.1	0.0	AIF(1,1,16, 2)
.96	3.77	.24	.09	39.9	0.0	AIF(5,1,16, 2)
8.62	5.85	.66	.14	48.1	0.0	AIF(1,1,16, 3)
1.46	3.61	.41	.08	44.7	0.0	AIF(8,1,16, 3)

where: M corresponds to the type of fuel considered in the option

N corresponds to the residential sector

NN corresponds to the activities of a single-family unit in the south

NI corresponds to the option

APPENDIX H

ALIGNMENT OF MODEL'S SHARES WITH TREE SHARES

ENERGY SHARE

ACTIVITY INPUT DATA SHARE				REFERENCE TREE SHARE		OUTPUT MODEL SHARE		NEW INPUT DATA SHARE		
RESIDENT.	NN	DD(NN)	DD(NN)/DD(1) DD#	SH*(NN)	SH*(NN)/SH*(1)	SH(NN)	SH(NN)/SH(1)	DD*(NN)/DD*(1) xDD#	DD*(NN)	
1		0.01779	1.00000	0.13039	1.00000	0.13079	1.00000	1.00000	1.00000	0.01760
2		0.00656	0.36875	0.03315	0.25424	0.03324	0.25415	1.00035	0.36888	0.00649
3		0.00127	0.07139	0.00663	0.05085	0.00663	0.05069	1.00307	0.07161	0.00126
4		0.06768	3.80438	0.05083	0.38983	0.05105	0.39032	0.99874	3.79961	0.06687
5		0.02782	1.56380	0.25311	1.94118	0.25382	1.94067	1.00026	1.56421	0.02753
6		0.00825	0.46374	0.06435	0.49352	0.06453	0.49339	1.00027	0.46387	0.00816
7		0.00247	0.13884	0.01287	0.09870	0.01290	0.09863	1.00074	0.13894	0.00245
8		0.13138	7.38505	0.09867	0.75673	0.09909	0.75763	0.99882	7.37630	0.12982
9		0.01245	0.69983	0.06027	0.46223	0.06048	0.46242	0.99958	0.69954	0.01231
10		0.01051	0.59078	0.02583	0.19810	0.02594	0.19833	0.99881	0.59008	0.01039
11		0.00413	0.23215	0.02153	0.16508	0.02158	0.16500	1.00051	0.23227	0.00409
12		0.05099	2.86622	0.03588	0.27514	0.03262	0.24941	1.10316	3.16189	0.05565
13		0.01422	0.79933	0.08673	0.66516	0.08708	0.66580	0.99904	0.79855	0.01405
14		0.01013	0.56942	0.03717	0.28507	0.03732	0.28534	0.99904	0.56887	0.01001
15		0.00595	0.33446	0.03098	0.23756	0.03108	0.23763	0.99968	0.33435	0.00588
16		0.08106	4.55649	0.05163	0.39593	0.05185	0.39644	0.99871	4.55064	0.08009
SUM		0.45266		1.00000		1.00000		16.10078	25.71962	0.45266

ENERGY SHARE

ACTIVITY INPUT DATA SHARE				REFERENCE TREE SHARE		OUTPUT MODEL SHARE		NEW INPUT DATA SHARE		
COMMERC.	NN	DD(NN)	DD(NN)/DD(1) DD#	SH*(NN)	SH*(NN)/SH*(1)	SH(NN)	SH(NN)/SH(1)	DD*(NN)/DD*(1) xDD#	DD*(NN)	
	1	0.00630	1.00000	0.19760	1.00000	0.19743	1.00000	1.00000	1.00000	0.00631
	2	0.00076	0.12063	0.01900	0.09615	0.01903	0.09639	0.99756	0.12034	0.00076
	3	0.00546	0.86667	0.08360	0.42308	0.08368	0.42385	0.99818	0.86509	0.00546
	4	0.00326	0.51746	0.07980	0.40385	0.07979	0.40414	0.99926	0.51708	0.00326
	5	0.00563	0.89365	0.17160	0.86842	0.17158	0.86907	0.99926	0.89299	0.00563
	6	0.00032	0.05079	0.00780	0.03947	0.00778	0.03941	1.00171	0.05068	0.00032
	7	0.00618	0.98095	0.08970	0.45395	0.08968	0.45424	0.99936	0.98033	0.00618
	8	0.00494	0.78413	0.12090	0.61184	0.12091	0.61242	0.99906	0.78339	0.00494
	9	0.00355	0.56349	0.11500	0.58198	0.11498	0.58238	0.99931	0.56311	0.00355
	10	0.00018	0.02857	0.00460	0.02328	0.00472	0.02391	0.97374	0.02782	0.00018
	11	0.00322	0.51111	0.05290	0.26771	0.05290	0.26794	0.99914	0.51067	0.00322
	12	0.00235	0.37302	0.05750	0.29099	0.05752	0.29134	0.99879	0.37257	0.00235
SUM		0.04215		1.00000		1.00000		11.96538	6.68426	0.04215

ENERGY SHARE

ACTIVITY INPUT DATA SHARE				REFERENCE TREE SHARE		OUTPUT MODEL SHARE		NEW INPUT DATA SHARE		
INDUSTR.	NN	DD(NN)	DD(NN)/DD(1) DD#	SH*(NN)	SH*(NN)/SH*(1)	SH(NN)	SH(NN)/SH(1)	DD*(NN)/DD*(1) xDD#	DD*(NN)	
1		0.01539	1.00000	0.11340	1.00000	0.11365	1.00000	1.00000	1.00000	0.01541
2		0.00175	0.11371	0.02310	0.20370	0.04083	0.35926	0.56701	0.06447	0.00099
3		0.00291	0.18908	0.07140	0.62963	0.07137	0.62798	1.00263	0.18958	0.00292
4		0.00009	0.00585	0.00210	0.01852	0.00215	0.01892	0.97890	0.00572	0.00009
5		0.00452	0.29370	0.11940	1.05291	0.11964	1.05271	1.00019	0.29375	0.00453
6		0.00527	0.34243	0.11000	0.97002	0.11019	0.96956	1.00048	0.34259	0.00528
7		0.00055	0.03574	0.01800	0.15873	0.01814	0.15961	0.99447	0.03554	0.00055
8		0.00050	0.03249	0.01700	0.14991	0.01713	0.15073	0.99460	0.03231	0.00050
9		0.00060	0.03899	0.01600	0.14109	0.01597	0.14052	1.00409	0.03915	0.00060
10		0.00059	0.03834	0.01560	0.13757	0.01568	0.13797	0.99709	0.03823	0.00059
11		0.00085	0.05523	0.03000	0.26455	0.03013	0.26511	0.99788	0.05511	0.00085
12		0.00102	0.06628	0.02550	0.22487	0.02542	0.22367	1.00536	0.06663	0.00103
13		0.00049	0.03184	0.01850	0.16314	0.01869	0.16445	0.99202	0.03158	0.00049
14		0.00016	0.01040	0.00500	0.04409	0.00489	0.04303	1.02475	0.01065	0.00016
15		0.00016	0.01040	0.00430	0.03792	0.00421	0.03704	1.02363	0.01064	0.00016
16		0.00176	0.11436	0.07000	0.61728	0.05109	0.44954	1.37315	0.15703	0.00242
17		0.00223	0.14490	0.06500	0.57319	0.06503	0.57220	1.00174	0.14515	0.00224
18		0.00286	0.18583	0.06000	0.52910	0.06011	0.52890	1.00037	0.18590	0.00286
19		0.00236	0.15335	0.04990	0.44004	0.04991	0.43916	1.00200	0.15365	0.00237
20		0.00012	0.00780	0.00410	0.03616	0.00417	0.03669	0.98538	0.00768	0.00012
21		0.00009	0.00585	0.00210	0.01852	0.00221	0.01945	0.95232	0.00557	0.00009
22		0.00135	0.08772	0.04960	0.43739	0.04978	0.43801	0.99858	0.08759	0.00135
23		0.00073	0.04743	0.01650	0.14550	0.01647	0.14492	1.00403	0.04762	0.00073
24		0.00064	0.04159	0.01100	0.09700	0.01101	0.09688	1.00129	0.04164	0.00064
25		0.00082	0.05328	0.02500	0.22046	0.02513	0.22112	0.99702	0.05312	0.00082
26		0.00064	0.04159	0.02000	0.17637	0.01988	0.17492	1.00825	0.04193	0.00065
27		0.00058	0.03769	0.01340	0.11817	0.01335	0.11747	1.00596	0.03791	0.00058
28		0.00052	0.03379	0.01200	0.10582	0.01195	0.10515	1.00640	0.03400	0.00052
29		0.00010	0.00650	0.00350	0.03086	0.00338	0.02974	1.03779	0.00674	0.00010
30		0.00008	0.00520	0.00200	0.01764	0.00192	0.01689	1.04396	0.00543	0.00008
31		0.00017	0.01105	0.00660	0.05820	0.00652	0.05737	1.01450	0.01121	0.00017
SUM		0.04990		1.00000		1.00000		31.01584	3.23817	0.04990

ENERGY SHARE

ACTIVITY INPUT DATA SHARE				REFERENCE TREE SHARE		OUTPUT MODEL SHARE		NEW INPUT DATA SHARE		
TRANSP.	NN	DD(NN)	DD(NN)/DD(1) DD#	SH*(NN)	SH*(NN)/SH*(1)	SH(NN)	SH(NN)/SH(1)	DD*(NN)/DD*(1) xDD#	DD*(NN)	
1		0.49157	1.00000	0.40000	1.00000	0.40012	1.00000	1.00000	1.00000	0.49149
2		0.07534	0.15326	0.07580	0.18950	0.07581	0.18947	1.00017	0.15329	0.07534
3		0.00205	0.00417	0.00700	0.01750	0.00698	0.01745	1.00259	0.00418	0.00205
4		0.00065	0.00132	0.00080	0.00200	0.00079	0.00196	1.01941	0.00135	0.00066
5		0.11589	0.23575	0.29640	0.74100	0.29636	0.74068	1.00044	0.23586	0.11592
6		0.01067	0.02171	0.02730	0.06825	0.02729	0.06820	1.00067	0.02172	0.01068
7		0.00105	0.00214	0.00270	0.00675	0.00269	0.00672	1.00402	0.00214	0.00105
8		0.03128	0.06363	0.08000	0.20000	0.07999	0.19992	1.00043	0.06366	0.03129
9		0.02088	0.04248	0.05340	0.13350	0.05340	0.13346	1.00030	0.04249	0.02088
10		0.00258	0.00525	0.00660	0.01650	0.00660	0.01650	1.00030	0.00525	0.00258
11		0.00390	0.00793	0.01000	0.02500	0.00997	0.02492	1.00331	0.00796	0.00391
12		0.01564	0.03182	0.04000	0.10000	0.04000	0.09997	1.00030	0.03183	0.01564
SUM		0.77150		1.00000		1.00000		12.03193	1.56973	0.77150

APPENDIX I

DERIVED FROM EIA DATA SOURCES

YEAR	ELECTRICITY				CRUDE OIL			
	TRILL. BTU	VALUE	\$/MILL. BTU	Ip=Py/Pb	TRILL. BTU	VALUE	\$/MILL. BTU	Ip=Py/Pb
1961	2839.2000	30294.2640	10.6700	1.1103	17422.9000	15680.6100	0.9000	0.4695
	3055.2000	31682.4240	10.3700	1.0791	17909.8000	16118.8200	0.9000	0.4695
	3276.8000	32899.0720	10.0400	1.0447	18354.4000	16518.9600	0.9000	0.4695
	3527.3000	33826.8070	9.5900	0.9979	18650.8000	16785.7200	0.9000	0.4695
	3782.7000	35103.4560	9.2800	0.9657	19137.7000	17223.9300	0.9000	0.4695
	4102.1000	36016.4380	8.7800	0.9136	20153.7000	18138.3300	0.9000	0.4695
	4353.1000	37219.0050	8.5500	0.8897	21042.9000	18938.6100	0.9000	0.4695
	4765.6000	38553.7040	8.0900	0.8418	21995.6000	19950.0092	0.9070	0.4732
	5169.7000	39444.8110	7.6300	0.7940	22546.1000	20088.5751	0.8910	0.4648
	5483.0000	40848.3500	7.4500	0.7752	23203.3000	20256.4809	0.8730	0.4554
1970	5785.4000	43332.6460	7.4900	0.7794	23583.4000	20635.4750	0.8750	0.4565
	6271.8000	47101.2180	7.5100	0.7815	24684.2000	20487.8860	0.8300	0.4330
	6670.0000	49358.0000	7.4000	0.7700	26356.6000	23826.3664	0.9040	0.4716
	6693.1000	56222.0400	8.4000	0.8741	25993.2000	47073.6852	1.8110	0.9448
	6874.1000	61798.1590	8.9900	0.9355	26398.9000	49841.1232	1.8880	0.9850
	7304.5000	66032.6800	9.0400	0.9407	28410.1000	52899.6062	1.8620	0.9714
	7615.0000	73180.1500	9.6100	1.0000	31437.4000	60259.2083	1.9168	1.0000
	7908.9000	74739.1050	9.4500	0.9834	31903.2000	59371.8552	1.8610	0.9709
	8056.1000	77177.4380	9.5800	0.9969	31903.2000	77556.6792	2.4310	1.2683
	8196.1000	84665.7130	10.3300	1.0749	29341.6000	103605.1896	3.5310	1.8421
1980	8226.1000	83988.4810	10.2100	1.0624	27457.5000	111038.1300	4.0440	2.1098
	8034.0000	96086.6400	11.9600	1.2445	25700.4000	86044.9392	3.3480	1.7467
	8281.6000	94410.2400	11.4000	1.1863	25319.3000	76211.0930	3.0100	1.5703
	8661.6000	78820.5600	9.1000	0.9469	26060.3000	74376.0962	2.8540	1.4889
	8853.5000	100310.1550	11.3300	1.1790	25700.4000	66358.4328	2.5820	1.3470
1985								

NATURAL GAS/WELL

TRILL.BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
12958.2000	4107.7494	0.3170	0.4096
13620.6000	4494.7980	0.3300	0.4264
14382.4000	4674.2800	0.3250	0.4199
15170.4000	4566.2904	0.3010	0.3889
15655.4000	4884.4848	0.3120	0.4031
16941.2000	5099.3012	0.3010	0.3889
17750.4000	5218.6176	0.2940	0.3798
18960.1000	5289.8679	0.2790	0.3605
20320.0000	5709.9200	0.2810	0.3630
21248.9000	5673.4563	0.2670	0.3450
21929.4000	5855.1498	0.2670	0.3450
22070.2000	5936.8838	0.2690	0.3475
21737.1000	6347.2332	0.2920	0.3773
21125.1000	7731.7866	0.3660	0.4729
19296.9000	9648.4500	0.5000	0.6460
19645.2000	12160.3788	0.6190	0.7997
18990.6000	14698.7244	0.7740	1.0000
19361.0000	16069.6300	0.8300	1.0724
19817.6000	19599.6064	0.9890	1.2778
19904.4000	24343.0812	1.2230	1.5801
19389.7000	26912.9036	1.3880	1.7933
17938.6000	29078.4706	1.6210	2.0943
16818.1000	27766.6831	1.6510	2.1331
17671.3000	28627.5060	1.6200	2.0930
17075.1000	24946.7211	1.4610	1.8876

NATURAL GAS/TRANSPORTED

TRILL.BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
12777.3000	6388.6500	0.5000	0.3595
13400.1000	6700.0500	0.5000	0.3595
14207.6000	7103.8000	0.5000	0.3595
15081.1000	7540.5500	0.5000	0.3595
15825.5000	7912.7500	0.5000	0.3595
17309.2000	8654.6000	0.5000	0.3595
18153.3000	10329.2277	0.5690	0.4091
19382.2000	9477.8958	0.4890	0.3515
20143.0000	10333.3590	0.5130	0.3688
21575.3000	11176.0054	0.5180	0.3724
22252.3000	12060.7466	0.5420	0.3896
22364.9000	12501.9791	0.5590	0.4019
22031.8000	12910.6348	0.5860	0.4213
21397.7000	15406.3440	0.7200	0.5176
19645.6000	18899.0672	0.9620	0.6916
19736.5000	24216.6855	1.2270	0.8821
19084.9000	26547.0959	1.3910	1.0000
19388.8000	28152.5376	1.4520	1.0439
19954.3000	31767.2456	1.5920	1.1445
20444.1000	37964.6937	1.8570	1.3350
20086.8000	42443.4084	2.1130	1.5191
18371.3000	44495.2886	2.4220	1.7412
17422.0000	41185.6080	2.3640	1.6995
18312.1000	42850.3140	2.3400	1.6822
17784.0000	0.0000		0.0000

NATURAL GAS/DISTRIBUTED

TRILL. BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
4841.6000	7988.6400	1.6500	0.7692
4854.2000	8057.9720	1.6600	0.7739
5010.7000	8367.8690	1.6700	0.7786
5325.1000	8946.1680	1.6800	0.7832
5510.9000	9313.4210	1.6900	0.7879
5950.1000	10115.1700	1.7000	0.7925
6470.6000	11122.9614	1.7190	0.8014
6732.4000	10967.0796	1.6290	0.7594
7196.4000	11211.9912	1.5580	0.7263
7464.4000	11413.0676	1.5290	0.7128
7711.8000	11783.6304	1.5280	0.7124
7948.9000	12312.8461	1.5490	0.7221
7674.5000	11872.4515	1.5470	0.7212
7548.5000	11941.7270	1.5820	0.7375
7623.2000	13409.2088	1.7590	0.8200
7913.0000	15343.3070	1.9390	0.9040
7505.0000	16098.2250	2.1450	1.0000
7725.0000	17164.9500	2.2220	1.0359
8047.1000	19441.7936	2.4160	1.1263
7521.9000	20579.9184	2.7360	1.2755
7353.2000	21463.9908	2.9190	1.3608
7435.5000	24552.0210	3.3020	1.5394
6993.8000	25974.9732	3.7140	1.7315
7278.2000	26055.9560	3.5800	1.6690
7031.5000	25313.4000	3.6000	1.6783

FUEL OIL/LIGHT

TRILL. BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
13500.8000	34508.0448	2.5560	0.8718
14145.8000	35180.6046	2.4870	0.8482
14547.6000	35132.4540	2.4150	0.8237
13975.0000	33078.8250	2.3670	0.8073
15096.2000	36185.5914	2.3970	0.8175
15791.5000	37899.6000	2.4000	0.8186
16502.4000	40430.8800	2.4500	0.8356
17671.6000	41952.3784	2.3740	0.8097
18433.9000	43080.0243	2.3370	0.7971
19006.8000	52819.8972	2.7790	0.9478
19755.0000	43480.7550	2.2010	0.7507
21040.9000	42965.5178	2.0420	0.6965
21957.7000	46418.5778	2.1140	0.7210
21202.2000	61740.8064	2.9120	0.9932
21246.9000	63464.4903	2.9870	1.0188
22422.1000	65607.0646	2.9260	0.9980
23479.6000	68842.1872	2.9320	1.0000
24025.3000	68760.4086	2.8620	0.9761
23095.3000	100395.2691	4.3470	1.4826
21183.1000	117036.6275	5.5250	1.8844
21007.9000	103526.9312	4.9280	1.6808
20551.9000	93613.9045	4.5550	1.5535
20830.5000	90341.8785	4.3370	1.4792
21537.2000	87484.1064	4.0620	1.3854
21815.2000	84708.4216	3.8830	1.3244

FUEL OIL/HEAVY

TRILL. BTU	VALUE	\$/MILL. BTU	Ip=Py/Pb
4894.6000	4361.0886	0.8910	0.4680
5145.2000	4213.9188	0.8190	0.4301
5150.8000	4192.7512	0.8140	0.4275
6260.5000	4895.7110	0.7820	0.4107
5968.8000	4661.6328	0.7810	0.4102
6330.2000	4659.0272	0.7360	0.3866
6522.7000	4455.0041	0.6830	0.3587
6734.9000	4195.8427	0.6230	0.3272
7170.5000	4123.0375	0.5750	0.3020
7702.4000	5638.1568	0.7320	0.3845
7934.8000	7276.2116	0.9170	0.4816
8667.3000	7263.1974	0.8380	0.4401
9515.5000	8963.6010	0.9420	0.4947
9113.5000	20086.1540	2.2040	1.1576
8618.0000	17666.9000	2.0500	1.0767
9708.9000	17097.3729	1.7610	0.9249
10405.2000	19811.5008	1.9040	1.0000
10804.1000	18280.5372	1.6920	0.8887
10685.1000	22812.6885	2.1350	1.1213
10093.5000	27757.1250	2.7500	1.4443
8132.9000	26293.6657	3.2330	1.6980
6853.4000	19868.0066	2.8990	1.5226
5802.1000	14505.2500	2.5000	1.3130
6366.9000	16159.1922	2.5380	1.3330
5889.1000	12696.8996	2.1560	1.1324

LIQUEFIED PETROLEUM GASES

TRILL. BTU	VALUE	\$/MILL. BTU	Ip=Py/Pb
870.6000	1480.0200	1.7000	0.7134
952.2000	1618.7400	1.7000	0.7134
1033.9000	1757.6300	1.7000	0.7134
1101.0000	1871.7000	1.7000	0.7134
1142.7000	1942.5900	1.7000	0.7134
1210.7000	2058.1900	1.7000	0.7134
1278.7000	2173.7900	1.7000	0.7134
1428.4000	2428.2800	1.7000	0.7134
1659.6000	2821.3200	1.7000	0.7134
1659.6000	2866.1292	1.7270	0.7247
1700.4000	2841.3684	1.6710	0.7012
1931.7000	5066.8491	2.6230	1.1007
1972.5000	4140.2775	2.0990	0.8808
1918.1000	5190.3786	2.7060	1.1355
1809.3000	4695.1335	2.5950	1.0890
1904.5000	5035.4980	2.6440	1.1095
1931.9000	4603.7177	2.3830	1.0000
1918.1000	4937.1894	2.5740	1.0802
2162.9000	6810.9721	3.1490	1.3214
1999.7000	7262.9104	3.6320	1.5241
1999.7000	7140.9287	3.5710	1.4985
2040.5000	7445.7845	3.6490	1.5313
2054.1000	7635.0897	3.7170	1.5598
2135.7000	7902.0900	3.7000	1.5527
2190.2000	8059.9360	3.6800	1.5443

COAL

TRILL.BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
10616.9000	4463.3448	0.4204	0.4526
10996.2000	4421.5720	0.4021	0.4329
11778.1000	4560.4803	0.3872	0.4168
12308.7000	4774.5447	0.3879	0.4176
12970.0000	4896.1750	0.3775	0.4064
13513.9000	5062.3069	0.3746	0.4033
13267.6000	4954.1218	0.3734	0.4020
13735.8000	4959.9974	0.3611	0.3887
13953.6000	5123.7619	0.3672	0.3953
14229.6000	6326.4802	0.4446	0.4786
13164.0000	6362.1612	0.4833	0.5203
13606.7000	6819.6780	0.5012	0.5396
14427.1000	7579.9983	0.5254	0.5656
14312.2000	12882.4112	0.9001	0.9690
14430.9000	14555.0057	1.0086	1.0858
15257.8000	14656.6427	0.9606	1.0341
15375.2000	14282.0233	0.9289	1.0000
14831.6000	14333.2582	0.9664	1.0404
16806.2000	16044.8791	0.9547	1.0278
17872.8000	16257.0989	0.9096	0.9792
18905.6000	16903.4970	0.8941	0.9625
18140.1000	15789.1430	0.8704	0.9370
18024.1000	14498.5860	0.8044	0.8660
19260.7000	14707.4705	0.7636	0.8220
20064.0000	14622.6432	0.7288	0.7846

WOOD

TRILL.BTU	VALUE	\$/MILL BTU	Ip=Py/Pb
1294.2000	711.8100	0.5500	0.5000
1299.8000	701.8920	0.5400	0.4909
1323.0000	701.1900	0.5300	0.4818
1336.3000	694.8760	0.5200	0.4727
1333.3000	679.9830	0.5100	0.4636
1367.3000	683.6500	0.5000	0.4545
1338.3000	655.7670	0.4900	0.4455
1417.2000	680.2560	0.4800	0.4364
1438.5000	704.8650	0.4900	0.4455
1429.6000	800.5760	0.5600	0.5091
1431.0000	815.6700	0.5700	0.5182
1502.1000	976.3650	0.6500	0.5909
1528.1000	1069.6700	0.7000	0.6364
1538.3000	1615.2150	1.0500	0.9545
1496.9000	1721.4350	1.1500	1.0455
1711.5000	2053.8000	1.2000	1.0909
1835.6000	2019.1600	1.1000	1.0000
2035.0000	2442.0000	1.2000	1.0909
2148.7000	2685.8750	1.2500	1.1364
2218.4000	2329.3200	1.0500	0.9545
2236.3000	2236.3000	1.0000	0.9091
2395.0000	2275.2500	0.9500	0.8636
2556.0000	2300.4000	0.9000	0.8182
2633.0000	2238.0500	0.8500	0.7727
2750.0000	2200.0000	0.8000	0.7273

APPENDIX J

HISTORICAL AND MODEL PRICE COMPARISON (\$/MILLION BTU)

	1977	1961			1974		
	BASE YEAR	Ip (Mod)	Ip (EIA)	ERROR	Ip (Mod)	Ip (EIA)	ERROR
E	9.61000	1.22045	1.11030	0.09921	0.87399	0.87410	-0.00012
CO	1.91680	0.46465	0.46950	-0.01034	0.94126	0.94480	-0.00375
NG/W	0.77400	0.37522	0.40960	-0.08395	0.45600	0.47290	-0.03574
NG/T	1.39100	0.36130	0.35950	0.00500	0.51282	0.51760	-0.00923
NG/D	2.14500	0.69795	0.76920	-0.09263	0.64965	0.73750	-0.11912
FO/L	2.93200	0.86088	0.87180	-0.01252	0.95742	0.99320	-0.03602
FO/H	1.90400	0.86594	0.46800	0.85031	1.16924	1.15760	0.01006
LP6	2.83800	0.86781	0.71340	0.21644	1.09530	1.13550	-0.03541
C	0.92800	0.44502	0.45260	-0.01674	0.95787	0.96900	-0.01149
W	1.10000	0.53833	0.50000	0.07666	0.94987	0.95450	-0.00485

	1977			1985		
	Ip (Mod)	Ip (EIA)	ERROR	Ip (Mod)	Ip (EIA)	ERROR
E	1.00928	1.00000	0.00928	1.13321	1.17900	-0.03884
CO	1.00133	1.00000	0.00133	0.89534	1.34700	-0.33531
NG/W	1.00033	1.00000	0.00032	1.83022	1.88760	-0.03040
NG/T	1.00034	1.00000	0.00034	1.62892	1.68220	-0.03167
NG/D	1.00036	1.00000	0.00036	1.63692	1.67830	-0.02465
FO/L	1.00298	1.00000	0.00298	1.30231	1.32440	-0.01668
FO/H	1.00178	1.00000	0.00178	1.19077	1.13240	0.05155
LP6	1.00109	1.00000	0.00109	1.46128	1.54430	-0.05376
C	1.00515	1.00000	0.00515	0.75959	0.78460	-0.03187
W	1.00038	1.00000	0.00038	0.73842	0.72730	0.01529

Ip (Mod): Model Indexed Prices

Ip (EIA): EIA Indexed Prices

ERROR = [Ip (Mod) - Ip (EIA)] / [Ip (EIA)] - 1

SHORT USER'S GUIDE

The GEM is designed to compute the levels of operation X_j for each process $j=1,M$ and optimum prices P_i for each sector $i=1,N$.

Input data required are programmed in subroutines INPUT and INPRICE included in Appendix A, and is presented in Appendix B according to the following definitions:

RN	Elasticity parameters for demand processes (CES)
RY	Exponent of the final demand share function (logit)
RT	Exponent of the fuel option share function for each demand process
BPFU	Base fuel prices
CY	Lag parameter for final demand
CA	Lag parameter for input vector processes
YA	Sectors final demand share
NZ,JZ	Specification of levels of operation (bounds)
NUMNI	Specification of fuel options within: NUMNN
NUMNN	Activities of each demand sector: NUMN
NUMN	Residential, Commercial, Industrial, Transportation, Import
AA	Output vector (output of good i from a unit of operation of process j)

AB	Input vector (input of good i to a unit of operation of process j)
AIF	Engineering-economic-energy coefficients for demand sectors specifying EKLM for each activity and fuel option
PK	Price of capital for selected years
PL	Price of labor for selected years
YT	Gross National Product (GNP)
TX	Tax for each process for selected years
DD	Cost share coefficients (for CES function) for each demand process within the specific activities and for selected years
DF	Share coefficients for final demand (for logit function) and for selected years
Z	Constraints on level of production for each process and for selected years

An LP problem is solved by subroutine ZX4LP from ISML library; see Appendix C. Special attention must be placed on the dimension of the arguments.

Intermediate outputs of the model at the base year, needed for calibration and validation, are defined next:

XA	Output coefficients
XB	Input coefficients
GZ	Relations between capital, labor, real GNP, GNP

PN	Average cost of energy for each process demand and for each activity
AEF	Energy shares for each sector and each activity within each process demand
DD	Cost share coefficients
G	Unit cost function
SH	Energy share coefficients (can be switched on/off for convenience)
ANB	Energy share coefficients for demand sectors

Final outputs of the model for each year are defined
next:

PSOL	Primal solution (quantity solution)
VXP	Excess of profit
VA, V	Value added for each process
PP	Indexed prices for each sector
DSOL	Dual solution (price solution)
VAD	Value added
GNP	Gross National Product
RGNP	Real Gross National Product
QCAP	Capital
QLAB	Labor
EA	Energy supply from each process
EB	Energy demand for each process

Projections can be made by acting over the following parameters:

- NYR Limiting the time scenario
- PK,PL Placing weight factors on the unit prices of capital and labor, which is useful for policy analysis
- TX Increasing or decreasing taxes in specific periods, which affects prices and demand
- Z Tightening or loosening the bounds of production for specific years, which affect the energy supply shares
- GNP Varying the Gross National Product by assuming that different rates of growth produce different economic scenarios

APPENDIX L

TABLE A. INPUT-OUTPUT ENERGY AGGREGATED TABLE (1000000 US\$ PRODUCERS' PRICE, 1977) First Part

	ELECTRICITY		CR. PETR. & NAT. GAS		GAS PROD. & DISTR.		PETROL. REFINING		COAL	
	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE
ELECTR.			486.5		105.2		588.7		269.3	
	63688.0									
CP. & N. GAS			2302.1		13147.5		60031.7			
			43384.8		86.2					
GAS P&D	4229.5		195.0		17028.1		1503.1		2.8	
			2306.7		44727.1					
PETR. REF.	8181.9		210.6		174.5		6105.6		242.6	
			3264.1		30.2		84353.3			
COAL	7259.4						1.5		2451.0	
			2.0						16635.8	
RESIDENT.										
COMMERC.	3496.1		6674.9		979.6		4480.2		1542.1	
	139.4						7.4			
INDUSTR.	5046.4		5015.0		420.7		4986.3		2375.1	
	40.7		125.5		143.0		8834.4		17.3	
TRANSP.	2273.9		205.1		64.8		2969.5		127.9	
CAPITAL	25005.8		30423.9		9160.1		8118.2		4058.0	
LABOR	8375.1		3570.0		3905.9		4410.3		5584.3	
SUM: MAKE	63868.1		49083.1		44986.5		93195.1		16653.1	
SUM: MAKE	63868.1		49083.1		44986.5		93195.1		16653.1	

TABLE A. (Continuation)

Second Part

	RESIDENTIAL		COMMERCIAL		INDUSTRIAL		TRANSPORTATION		EXPORT/IMPORT	
	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE
ELECTR.	30666.8		15286.8		15705.1		885.5		67.2	
				16.0						352.6
CP.&N.GAS	905.2				1916.9		78.9		202.2	
						51.6				35062.0
GAS P&D	12611.8		5409.1		8496.0		179.4		205.8	
				936.0		43.7				1847.1
PETR.REF.	981.3		9976.7		17460.4		54491.9		2206.2	
						1089.6				11294.5
COAL	515.1		22.6		4382.4		3.8		2096.3	
						8.3				86.2
RESIDENT.										
		177492.6								
COMMERC.	11462.8		253162.6		206669.8		17962.9		63724.3	
				1465721.3		21221.4		1334.0		29176.7
INDUSTR.	13348.4		114817.2		735031.4		11385.8		103789.4	
				24.9		1645650.3		34.2		103891.8
TRANSP.	9.3		16556.1		36568.9		16664.9		9756.4	
				1383.2		14.5		172546.4		332.3
CAPITAL	106991.3		385175.0		222262.0		19813.9			
LABOR			667675.3		419586.5		52447.6			
SUM:MAKE	177492.6		1468081.4		1668074.4		173914.6		182047.8	
SUM:MAKE		177492.6		1468081.4		1668074.4		173914.6		182043.2

TABLE A. (Continuation) Third Part (End)

	FINAL DEMAND		SUM:USE	SUM:MAKE
	USE	MAKE		
ELECTR.			64056.6	
				64056.6
CP.&N.GAS			78584.6	
				78584.6
GAS P&D			49860.6	
				49860.6
PETR.REF.			100031.7	
				100031.7
COAL			16732.2	
				16732.2
RESIDENT. 177492.6			177492.6	
				177492.6
COMMERC. 974444.9			1517600.2	
				1517600.2
INDUSTR. 762546.0			1758762.1	
				1758762.1
TRANSP. 89079.6			174276.4	
				174276.4
CAPITAL			811008.1	
LABOR			1165555.0	
SUM:MAKE 1976563.1			3891716.1	
SUM:MAKE				3891716.1

APPENDIX L

TABLE B. NEW INPUT-OUTPUT ENERGY TABLE (1000000 US \$ PRODUCERS' PRICE, 1977)

First Part

	E/H		E/N		E/C		E/O		E/G		E/W	
	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE
E	949.3		1077.1		4235.1		1533.4		1314.4		18.3	
CO		7228.4		8226.5		32313.4		11734.4		10015.5		133.2
NG/W												
NG/T									4530.3			
NG/D												
FO/L							828.7					
FO/H							6881.4					
LP6												
C					9521.5							
W											2.5	
SUM:E. USE	949.3		1077.1		13756.6		9243.5		5844.7		20.8	
SUM:E. MAKE RESIDENT.		7228.4		8226.5		32313.4		11734.4		10015.5		133.2
COMMERC.	2050.7		2351.8								31	
INDUSTR.	524.5		595.2		2340.4	308.5	847.4	4339.7	726.3	1683.8	10.1	
TRANSP.	236.5	4.2	268.3	4.8	1055.1	18.9	382	6.8	327.4	5.9	4.6	0.1
SUM:M. USE	2811.7		3215.3		3395.5		1229.4		1053.7		45.7	
SUM:M. MAKE		4.2		4.8		327.4		4346.5		1689.7		0.1
CAPITAL	2600.6		2950.6		11602.7		4201		3600.8		50	
LABOR	871		988.3		3886		1407		1206		16.8	
TOTAL:USE	7232.6		8231.3		32640.8		16080.9		11705.2		133.3	
TOTAL:MAKE		7232.6		8231.3		32640.8		16080.9		11705.2		133.3

TABLE B. (Continuation)

Second Part

	CD		NG/W		NG/T		NG/D	
	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE
E	286.2		359.1					
CD		33448.3						
NG/W			1311.8		12968.1			
				14698.7				
NG/T							9004.1	
					26547.1			
NG/D								
FO/L	153		192.1		87.2		87.3	13884.8
FO/H								
LP6				2632.9				
C		0.9		1.1				
W								
SUM:E. USE	439.2		1863		13055.3		9091.4	
SUM:E. MAKE		33449.2		17332.7		26547.1		13884.8
RESIDENT.								
COMMERC.	7612.8		1768.6		7377.4		1910.9	
						2601.1		1810.5
INDUSTR.	3259.7		1755.3		273.5		147.2	
		71.8		43.9		93		50
TRANSP.	133.3		71.8		42.1		22.7	
SUM:M. USE	11005.8		3595.7		7693		2080.8	
SUM:M. MAKE		71.8		43.9		2694.1		1860.5
CAPITAL	19755.5		10668.4		5954.1		3206	
LABOR	2320.5		1249.5		2538.8		1367.1	
TOTAL:USE	33521		17376.6		29241.2		15745.3	
TOTAL:MAKE		33521		17376.6		29241.2		15745.3

TABLE B. (Continuation)

Third Part

	FO/L USE	MAKE	FO/H USE	MAKE	LPG USE	MAKE	C USE	MAKE	W USE	MAKE
E	630.8		251.8		51.3		338.9		4.3	
CO	39990.3		15972.6		3282.2					
NG/W										
NG/T	906.3		361.5		1973.8					
NG/D										
FO/L	19.1		7.6		1.6		175.4		13.7	
FO/H	64.8	65114.5	25.9		5.2		15.2			
LPG				13682.5						
C	2.6		1		0.2	1356.3	3.5			
W								14191.7		
SUM:E,USE	41613.9		16620.4		5314.3		533		18	2019.2
SUM:E,MAKE RESIDENT.		65114.5		13682.5		1356.3		14191.7		2019.2
COMMERC.	17456.4						3974.8		715.3	
INDUSTR.	4050.9	3420.1	851.1	4926.5	84.3	4155	2375.1	2444.1	415.8	
TRANSP.	2412.4	7177.1	506.9	1508	50.2	149.3	127.9	17.3	23.5	
SUM:M,USE	23919.7		1358		134.5		6477.8		1154.6	
SUM:M,MAKE		10597.2		6434.5		4304.3		2461.4		0
CAPITAL	6595.2		1385.8		137.2		4058		353.2	
LABOR	3582.9		752.8		74.6		5584.3		493.4	
TOTAL:USE	75711.7		20117		5660.6		16653.1		2019.2	
TOTAL:MAKE		75711.7		20117		5660.6		16653.1		2019.2

TABLE B. (Continuation)

Fourth Part

	RESIDENTIAL		COMMERCIAL		INDUSTRIAL		TRANSPORTATION		EXPORT	IMPORT
	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE	USE	MAKE
E	22680.6		16320.2		22905.1		138.1		90.2	
CD					893.2	2871.6			202.8	661.2
NG/W							418.8			26892.8
NG/T					9685.8				85.3	
NG/D	10621.6		5475.1							2211.9
FO/L	6318		2422.6		5281.2		52944		100.4	3517.4
FO/H			1119.6		9878.2		1729.8		91.4	6129
LPB	1514.1		267.1		3529.8		103.6		68.1	615.8
C	78.5		113.7		3191.8	877.7	0.2		1368.3	79.3
W	596		11.3		1409.4	8.3				
SUM:E.USE	41808.8		25729.6		56774.5		55334.5		2006.5	
SUM:E.MAKE		0		0		3757.6		0		40107.4
RESIDENT.		177492.6								
COMMERC.	15930.4		258139.5		198532.2		18267.9		66491	
INDUSTR.	12752.8		114805.9	1466673.3	733206.2	18657	11385.8	1334	103789.4	37702
TRANSP.	9.3		16556.1	24.9	36545.4	1643631.1	16664.9	34.2	9756.4	103901.6
SUM:M.USE	28692.5		389501.5	1383.2	968283.8	14.5	46318.6	172546.4	180036.8	332.3
SUM:M.MAKE		0		1468081.4		1662302.6		173914.6		141935.9
CAPITAL	106991.3		385175		221908.8		19813.9			
LABOR			667675.3		419093.1		52447.6			
TOTAL:USE	177492.6		1468081.4		1666060.2		173914.6		182043.3	
TOTAL:MAKE		177492.6		1468081.4		1666060.2		173914.6		182043.3

TABLE B. (Continuation)

Fifth Part (End)

FINAL DEMAND		TOTAL		STANDARD AND CONVENTIONAL ENERGY PRICES				
USE	MAKE	SUM:USE	SUM:MAKE	⁶ \$/10 BTU	CONVERSION FACTOR	UNIT	CONVENTIONAL UNIT PRICE	UNIT
E		73184.2						
			73184.2	9.61	3,412	BTU/KWH	0.03279	\$/KWH
CO		60341.1						
			60341.1	1.9168	5.8	10 BTU/BBL	11.117	\$/BBL
NG/W		14698.7						
			14698.7	0.774	1,019	BTU/CF	0.789	\$/10 ³ CF
NG/T		26547.1						
			26547.1	1.391	1,019	BTU/CF	1.417	\$/10 ³ CF
NG/D		16096.7						
			16096.7	2.145	1,019	BTU/CF	2.186	\$/10 ³ CF
FO/L		68631.9						
			68631.9	2.932	5.45	10 ⁶ BTU/BBL	15.93	\$/BBL
FO/H		19811.5						
			19811.5	1.904	6.28	10 ⁶ BTU/BBL	11.95	\$/BBL
LP6		5482.7						
			5482.7	2.838	3.7	10 ⁶ BTU/BBL	10.5	\$/BBL
C		14281.3						
			14281.3	0.9289	22.29	10 ⁶ BTU/ST	20.705	\$/ST
W		2019.2						
			2019.2	1.1	17.2	10 ⁶ BTU/ST	18.92	\$/ST
SUM:E. USE		301094.4						
SUM:E. MAKE			301094.4					
RESIDENT.	177492.6	177492.6						
			177492.6					
COMMERC.	947444.9	1550055.6						
			1550055.6					
INDUSTR.	762546	1756742.9						
			1756742.9					
TRANSP.	89079.6	174276.4						
			174276.4					
SUM:M. USE								
SUM:M. MAKE								
CAPITAL		811008.1						
LABOR		1165555						
TOTAL:USE	1976563.1							
TOTAL:MAKE		0						

VITA

Raul Smith-Fontana was born in Antofagasta, Chile, on February 26, 1937. He attended schools in Valparaiso and Antofagasta and graduated from the Military High School General Bernardo O'Higgins. He became a Lieutenant of the Chilean Army in 1954.

For the next 11 years, he served in several places and was admitted to the Military Polytechnical Academy, where he graduated as a chemical engineer in 1962.

He married Maria Luisa Puigredon in 1963 and was promoted to Captain in 1964.

Mr. Smith-Fontana retired from the army in 1965 to become a full-time faculty member of the Engineering School of Catholic University of Chile where he lectured on mathematics. At the same time he accepted a part-time teaching position in Chemical Engineering at the Technical State University currently the University of Santiago of Chile.

In 1967 a Ford Foundation fellowship was awarded to him to study at New York University where he graduated in 1969 as a Master of Science in applied mathematics from the Courant Institute of Mathematical Sciences.

In 1970 he accepted the position of Academic Director of Institute of Mathematics of the Catholic University of Chile, a new academic structure within the university.

A second Ford Foundation fellowship was granted to him

in 1972 to continue studies for the Ph.D. at the Courant Institute of Mathematical Sciences.

Mr. Smith-Fontana interrupted his studies in 1974 and went back to Chile to the position of Head of Planning of the Chilean Nuclear Energy Commission.

In 1976 he accepted the position of Head of Planning for a national nuclear power project. Within this project he was trained at a nuclear power plant in Spain and at the Argonne National Laboratory in the United States.

He left the nuclear power project in 1980, when the government decide to postpone it. He accepted a position as the Dean of the College of Engineering at the University of Santiago of Chile.

In 1981 he signed an agreement of cooperation with the College of Engineering of the University of Tennessee and with the Institute of Energy Analysis of Oak Ridge Associated Universities.

Late in 1983 he accepted a position as General Secretary of the University of Santiago of Chile.

Mr. Smith-Fontana was admitted to a Ph.D. engineering program at the University of Tennessee and arrived in Knoxville late in December 1983 with his wife Maria Luisa and sons and daughter Raul, Alejandro, Javier and Maria Luisa.