ENERGY LABORATORY

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

ENERGY LABORATORY DATA AND MODEL DIRECTORY

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FOREWORD

Over the past several years M.I.T. faculty, staff, and students have produced a substantial body of research and analysis relating to the production, conversion, and use of energy in domestic and international markets. Much of this research takes the form of models and associated data bases that have enduring value in policy studies (models) and in supporting related research and modeling efforts (data). For such models and data it is important to ensure that the useful life cycle does not end with the conclusion of the research project.

In an effort to develop a mechanism for supporting the maintenance and appropriate access to Energy Laboratory associated models and data, the Laboratory's Center for Energy Policy Research (CEPR) has sponsored a project to prepare this Energy Laboratory Data and Model Directory, edited by Dr. Supriya Lahiri and Ms. Jacqueline Carson. The Directory provides a survey of selected models and data bases and includes descriptive information, current status, mode of access, and contact persons. This directory represents the conclusion of this project.

This directory is an important step in extending the usefulness of models and data bases available here at the M.I.T. Energy Laboratory. It will be updated from time to time to include new models and data bases that have been developed, or significant changes that have occurred in the entries included here. You suggestions and comments are welcome.

David O. Wood
Program Director
Energy Markets, Pricing, and Regulation

I. COMPLETED RESEARCH MODELS AND ASSOCIATED DATA COLLECTIONS

1.1. MODEL HISTORY

a. Name: Regionalized Electricity Model (REM)

b. Developers: Martin L. Baughman, Massachusetts Institute of Technology, Cambridge, Massachusetts, currently at The University of Texas, Austin

Paul L. Joskow, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration:* 1972 to 1976

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts; University of Texas, Austin

e. Sponsors: Development of the model began at MIT under the auspices of the MIT Energy Laboratory under grants from NSF. This work has continued at MIT and Texas at Austin under grants from the NSF, the FEA, the Energy Research and Development Administration, the Electric Power Research Institute, and the Ford Foundation.

1.2 MODEL DESCRIPTION

a. Summary

The Baughman-Joskow Regionalized Electricity Model (REM) is a comprehensive engineering econometric model of the U.S. electric power sector. It combines a behavioral model of the demand for electricity and competing fuels with a process engineering approach to determine supply response, all conditioned by the fact that the industry is regulated. The model combines these three components into a single integrated system. As such, it provides a useful framework for the analysis of policy-related issues affecting the industry and electric consumers.

Some key features of REM are:

(1) The overriding objective of REM is analysis of policy issues affecting the electric utility industry. The model is intended to assist in the decision-making processes of electricity producers, users, and regulators;

(2) REM is designed to simulate or replicate the behavioral processes observed in the electric utility industry. It is not designed as an optimization model except to the extent that decision makers themselves follow optimization rules;

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*Throughout this directory, "duration" refers to that period of time in which the modelers were actively engaged in working on the model.

(3) REM deals with the supply, demand, and regulatory aspects of the electric utility industry in a simultaneous integrated fashion; and

(4) REM operates on a regional level of disaggregation; it does not separately address the decision-making processes in the individual electric utilities. A primary function of the regionalization is to improve the model's applicability to national issues.

The completed model has been used to develop a set of "policy studies." The model has been used to examine alternative courses of future electricity consumption and fuel utilization for the electric utility industry as a whole, as well as for the nine census regions. Specifically, the sensitivity of electricity demand and fuel utilization to changes in the expected costs of coal, uranium, coal-powered plants, nuclear-powered plants, and economic growth trends over the time period to the year 2000 have been examined. The authors have also examined in detail the requirements for nuclear-powered plants and nuclear fuel-cycle requirements based on alternative economic and institutional developments. Finally, the capital requirements and financial prospects of the U.S. electric utility industry within the context of existing regulatory institutions, as well as in response to a variety of possible changes in the methods of determining electricity prices, have been examined.

The Regionalized Electricity Model is a dynamic model of the electricity market. As such, it is composed of quantitative descriptions of both the supply and demand sides of the market, which interact through the price of electricity. Common to both the supply and demand sides of the market are sets of decision rules that govern the dynamic change. Suppliers choose a mix and amount of production plants--generation, transmission, and distribution equipment--to supply electricity reliably, and at least cost to their consumers. Consumers choose among a set of energy input possibilities--coal, oil, natural gas, and electricity-- to meet their functional needs and maximize their personal satisfaction within their budget constraints. In both cases decisions are made based upon a set of stimuli, expectations, and goals. The Regionalized Electricity Model represents the authors' attempt to capture the more important of these rules in a mathematical description. In some cases, the description has been derived from experiencing and viewing the industry's behavior. In other cases, it has been deduced using standard statistical techniques.

The link between the supply and demand sides of the market for electricity is the price of electricity. The price of electricity is computed in REM accounting according to the rate-setting practices of state public utility commissions where the price of electricity is set to yield a predetermined rate of return on the utilities' rate base.

The Regionalized Electricity model (REM) is organized into three major components or submodels, including the demand, supply, and financial regulatory submodels. Figure 1 (see page 19) provides a the total cost of this financing, the financial/regulatory submodel passes back an estimate of the capital charge rate to the supply submodel. This is used in the generation expansion model as one of the factors determining the amount and type of capital investments in future time periods.

Finally, the financial/regulatory submodel determines the price of electricity and passes this on to the demand submodel. It is assumed that the regulatory process uses data from the current period to set the price for the coming period. Reflecting this, the price information that is given to the demand submodel is used to start the REM simulation for the next time period.

In addition to the information flows among submodels, there are a number of important exogenous inputs to REM. Some of the key exogenous factors are outlined in the ovals of Figure 1.

Thus, the REM model is composed of a mathematically expressed set of behavioral, accounting, and optimization rules. REM is descriptive, not normative, and thus not cast in the mathematically programming mold of many widely known energy modeling efforts. REM contains optimization concepts in parts of its structural detail, but overall it is formulated as a simulation tool with both engineering and economic detail.

In developing the REM model the primary goal was to develop an analytical tool that could be utilized to examine the effects of major national energy policy proposals on electricity prices, electricity demand, and fuel utilization by the electric utility industry.

Thus, the REM fully develops important methodological and analytical issues surrounding the structure and use of the model, as well as shedding some light on a number of important energy policy issues.

b. Data Base

The data collection that supports the REM submodels consists of several sections: U.S. energy demand and fuel prices for the residential commercial and industrial sectors, by state; transmission and distribution equipment and costs for electric power plants by type of generator and by region; generator characteristics and fuel prices; and regulatory financial parameters. The submodels then contribute a set of input parameters to develop a base case for the simulation.

Scope of the Data Collection

The model treats the U.S. as nine geographic regions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific. Some of the data are developed by state for the period 1960-1974 to support the estimation of equations for the demand submodel. Some variables are point estimates, or forecasted values, by region, for the simulation.

schematic overview of the structural components of REM, the linkages among submodels, and the major exogenous variables required to operate the model.

The function of the demand submodel is to estimate the amount of electricity demand in the current time period. Demand for electricity and competing fuels are broken into two major user categories, residential/commercial and industrial, since each consuming sector has different behavioral characteristics, and because the demand for electricity by each sector imposes different requirements on the supply system, particularly regarding transmission and distribution facilities. Demand for electricity and directly competing fuels are estimated for each consuming sector by state. The functional forms for equations and parameter values used are presented in Tables 1 and 2, respectively (see pages 21-22).

The major behavioral processes in the supply submodel are simulated in three components: electricity generation, generation expansion, and transmission and distribution. In addition, the supply submodel contains three modules that process the input data required by the generation expansion model. These modules deal with load prediction, exogenous factor forecasts, and the nuclear fuel cycle. A schematic outline of the relationship among these components is given in Figure 2.

The financial-regulatory submodel serves two functions. First it applies the tax, accounting, and regulatory rules of the industry to investment and operating costs of the supply system to determine the price of electricity, and thus closes the supply and demand portions of the model. Second, it simulates the financing of future expansion within the normal guidelines of prudent financial management while maintaining consistency with the income and cash flow accounts and the exogenously supplied costs of alternative forms of capital. By including a regulatory component, REM explicitly recognises that the price of electricity is not set in competetive markets; rather, it is determined by state and federal regulatory authorities using fairly well-established administrative procedures.

The four principal linkages among the REM submodels are indicated by the curved arrows in Figure 1. The demand submodel provides the supply submodel with estimates of the residential/commercial and industrial demands for electricity, the sum of which is the total electricity that must be produced during the current period. Current electricity demand is also an input to the load-prediction component of the supply submodel, where it is combined with previous demands to forecast future demands for electricity.

The supply submodel provides the financial/regulatory submodel with two primary inputs: production costs and current capital expenditures. These cost estimates are used in the financial/regulatory submodel to determine the revenue requirements of electric utilities and the rate base on which the regulated rate of return is to be calculated. The estimates of capital expenditures are also used to determine the total amount of financing required in the current period. After calculating

The data were converted from kWh into Btus. The range of years available is 1960-1974. Maryland and D.C. sales are combined in the publication, and this figure was split by assigning half to each district. The source used for the residential/commercial sectors' consumption of oil was the Bureau of Mines Mineral Industry Survey's table on "Shipments of Fuel Oil and Kerosine." The data are reported by grade of fuel oil; grades 1-4 were considered assignable to the residential sector and grades 5 and 6 assignable to the commercial sector. The data, reported in barrels, were converted to Btus according to the appropriate fuel grade conversion factor.

Other Variables

A data file was constructed for the average temperature of the three coldest months and the three warmest months, by state. An annual average of the normal monthly average was also calculated. The source of this data is National Oceanic and Atmospheric Administration publications, for the period 1941-1970.

A consumer price index for all items was constructed. The "Anderson" index for 1970, by state, was used to convert the Bureau of Labor Statistics nationwide CPI. The Anderson index is based on the relative living cost within the SMSAs, available from the Bureau of Labor Statistics, then adjusts this to account for non-metropolitan areas. This deflator assumes uniform inflation rates over all states.

Industrial Sector

In the industrial sector portion of the demand submodel, value-added in manufacturing, price of capital services, and an average energy price were required to estimate total national energy demand. A state's share of the national total is a function of relative state energy costs and population. State fuel demand is divided into the four fuels--coal, gas, oil, and electricity--as a function of relative prices. The data collection that supports this estimation is described below. The cross-sectional time series now stored usually cover the years 1962-1974.

Fuel Prices

The industrial price of natural gas was calculated from data in the Bureau of Mines Minerals Yearbook. The "value and consumption" table does not break out electric utilities through 1967; therefore (total - (residential and commercial)) was used to derive the prices. The descriptive comments for all the data files indicate that the data were converted from MCF to \$/Btu by using conversion factors for electric utilities from EEI. The industrial price of oil was constructed using the 1962 average value of the industrial (residual and distillate) oil price from the Census of Manufacturers, by state. This price was then extended through 1972, using the yearly percentage increases in number 2 fuel oil from the AGA's House-Heating Survey, by state gas utility (see the residential/commercial sector). Data for 1969 were not available and were constructed by interpolation. The units are dollars/Btu. The price of electricity was derived from the EEI's Statistical Yearbook

Public sources were used when adequate, and public utility representatives were interviewed when published information was not available.

Demand Submodel Data Collection

The demand submodel focuses on two sectors: the residential/commercial and the industrial. For both sectors, energy demand and prices were required, in addition to some economic indicators and temperature data. The actual estimates were derived from the 1968-1972 period.

Residential Commercial Sector

For the residential/commercial sector of the demand submodel, consumption per capita was required as a function of a weighted energy price. Fuel-split equations were also estimated, as functions of the relevant fuel prices and temperature.

Fuel Prices

The price of natural gas by state was obtained from the U.S. Bureau of Mines' Mineral Yearbook for the years 1962-1974. The price is derived from value/quantity as reported for the residential and commercial sectors. Where the data are aggregated for some states, the values are equally split and apportioned to the states. A weighted average price is then obtained with each sector's consumption used as weights. The price of electricity was derived from revenues and sales data, available in EEI's Statistical Yearbook for the years 1962-1974. Although there is a specific category for "residential," there is none for the commercial sector. Therefore, the category "small light and power" was assumed to be a comparable definition of the commercial sector. A weighted average price was calculated, using each sector's usage share of the fuel as weights. The final data files are in units of current dollars/Btu. An average oil price appropriate for the residential/commercial sector was not available to the researchers. The American Gas Association's price for number 2 fuel oil, by state, for the years 1962-1974, was used. The data are reported in the source in cents/gallon, and were converted to current dollars/million Btus.

Fuel Consumption

Data for the consumption of natural gas by residential and commercial sectors were obtained from the annual quantities by state tables in the Bureau of Mines Minerals Yearbook. The units were converted from million cubic feet to Btus using state-specific conversion factors in the EEI Statistical Yearbook of the Electric Utility Industry. Where the reported data were not completely disaggregated by state, the total was split and equally apportioned to the states. Annual sales data by state from the EEI Statistical Yearbook were used to derive electricity consumption. As described in the price data section, the commercial sector is not explicitly defined and the "small power and light" category was assumed to be comparable.

tables on revenue and sales, by state, for large light and power. This category includes some of the commercial sector and excludes some small industrial. Where states are aggregated, the quantity was equally split and apportioned to the states. The data were converted to dollars/Btu from kWh. The 1962 value for the industrial price of coal was obtained from the Census of Manufacturers. This was then extended to 1972 using the increases in the price of coal to electric utilities from the EEI's Statistical Yearbook. Where prices for states were unavailable, gaps in the data series were filled by adding transportation costs to the fuel prices of neighboring states. These transportation costs are all listed in the stored data files.

An average weighted price, by state, was calculated using consumption of each fuel as weights. This average state fuel price was then used to calculate a weighted average U.S. price, using each state's total industrial fuel consumption as weights.

Other Variables

Total resident population (including military) was obtained for all states for the period 1960-1974 from the Bureau of the Census. Data are published in thousands, and were converted to singular units. Land area for each state from the U.S. Statistical Abstract was also collected and stored and a data series for population/square mile/state was created.

Value-added, by state, for the years 1962-1972, was obtained from the Census of Manufacturers and the Annual Survey of Manufacturers. Data for the SIC codes 20-39 for all states are stored in separate data files for each year. These are then combined to form a file of the total for each state, years 1962-1972. There is also a file for total national value-added, years 1947-1971, but no source is indicated.

A price index with base year 1967 was used to deflate currency data. The data series range for the WPI is 1947 to 1974. There are separate series for an industrial price index, an industrial coal price index, and a refined oil products price index, but the source of these last three indices or the application to deflate specific prices series is not indicated.

Supply Submodel

Within the supply submodel, the nine regions each have five plant types plus the exogenously specified hydro available as supply alternatives. Each plant is characterized by a set of economic and technical data as a function of time; specifically, a capital cost, a fuel cost, an operation and maintenance cost, and a conversion efficiency. Each plant type is further assigned a forced outage rate, a duty cycle, and a lead time.

The relationship of transmission and distribution equipment to demand and the operation and maintenance cost have been estimated from historical data, while a structured analytical treatment was used for generation planning and electricity production. The data that supports the empirical work will be described in a separate section, because it is cross-sectional, time-series data, obtained for the most part from published sources. This portion of the supply submodel also interfaces with the demand submodel. The variables for generation and expansion are the results of simple expectation formation relationships based on point estimates.

Data Developed for the Purpose of Estimation

Operation and Maintenance Costs: Transmission and Distribution

The data collection ranges from 1967-1973, from three-year published averages. The components of cost are interactive in nature, and it is difficult to obtain accurate cost data; therefore, aggregate expenditures and equipment additions were used as average costs. Costs of transmission lines were obtained for the previously defined nine U.S. regions. This cost was defined as the ratio of the sum of undefined capital expenditures to the sum of new structure miles (or cable miles for underground) energized. Overhead and underground are divided into two categories: high volt and low volt. The source of these data is the "Annual Statistical Report" of Electrical World. The cost of primary distribution lines is derived in the same manner as cost of transmission lines and from the same source. The researchers report that the size of the sample for distribution lines is much larger than that for transmission lines; therefore, there is less variability and this series is more reliable. Three-year aggregate averages for transmission substation costs for the period 1953-1973 were obtained from the "Annual Statistical Report" of Electrical World. The units are dollars/kilowatt ampere of installed capacity.

Other Costs: Distribution Substations, Line Transformers, and Meters

There is no comprehensive source of data for these items. They are, however, not considered to be a major component of the cost of delivered electricity, and therefore not as important for the estimation. For these variables, point estimates were obtained from New England electric utility company representatives and other private sources.

Transmission and Distribution Equipment

This section of the supply submodel relates demand and other characteristics of a service area to the following six equipment items: transmission lines (in structure miles), transmission substations (in kilowatt amperes capacity), primary distribution lines (in circuit miles), distribution substations (in kilowatt amperes capacity), line transformers (in kilovolt amperes capacity), and meters (in number). These data were obtained for the period 1965-1972 from the Federal Power Commission's Statistics of Privately Owned Utilities. Privately owned utilities' data were deemed sufficient since they account for 80% of the entire electric utility industry and the data are more consistently reported. The equations derived from this estimation are preserved in the model, but the data collection is not presently available.

Generation Planning and Electricity Production

Fuel Costs

Fossil Fuel Prices

For the input base case, fossil fuel price start values are required. These data points, obtained for 1975 for fossil fuels, are an approximation of an historical price, derived in the following manner: A price at the minemouth or wellhead, as a national average, is the base, to which a transportation cost for each of the nine regions is added to derive a regional price. The source used for the price at the wellhead or minemouth is not cited, and the derivation of the transportation costs also is not described. However, all of the values used are presented in tables in Appendix D of Electric Power in the U.S. Escalation rates are used for the future years.

Although the source and derivation of the prices were not available at this writing, we are told that coal prices should be considered a composite price because the cost of coal scrubbers was incorporated where appropriate (for certain regions). The oil price for 1975 is an average of the three-tier domestic oil price and the imported price. Costs of transporting and refining are added to obtain regional prices.

Light Water Reactor Fuel Cycle

Nuclear fuel cycle costs that are used to determine nuclear fuel direct costs and carrying charges are exogenous to the model. The basic data from which the flow rates and total fuel cycle costs were calculated were obtained from ERDA. The 1975 unit costs obtained for Uranium Oxide feed, conversion enrichment/fabrication, shipping fresh and spent fuel, waste disposal, reprocessing, U credit and Pu credit, and carrying charges are presented in Appendix D of Electric Power in the U.S.

Capital Costs

A survey of a large number of utility companies throughout the U.S. and a review of estimates within the literature were undertaken to obtain capital costs for New England plants. The components of capital cost are the cost of the base plant, cost of the cooling plant system, cost of air pollution equipment, and interest during construction. Multipliers were used to convert the New England values to capital costs for each of the nine regions. These were obtained from the Atomic Energy Commission's publication, Power Plant Capital Costs, Current Trends and Sensitivity to Economic Parameters. Load factors by region were obtained from the Edison Electric Institute, the 55th Annual Election Power Survey, 1974.

Financial-Regulatory Submodel

The parameters used for the financial-regulatory submodel were the regulated return on equity, the cost of debt, the cost of preferred stock, the debt limit, the minimum interest coverage ratio, the preferred stock fraction, and the cost of SBB financing.

The regulated rate of return on equity is based on the rate base plus allowance for working capital. The valuation of the rate base chosen for this model was cost less accumulated depreciation, based on a 40-year lifetime. The allowance for working capital was calculated using the FPC formula for monthly billing companies. The source for the valuation of the rate base is not cited.

Operation and maintenance cost and fuel cost are from the output of the supply submodel. Taxes, depreciation, deferred taxes, allowances for interest during construction, investment tax credits, and preferred and common stock dividends are computed within the financial submodel.

c. Computer Aspects

The model is in the form of a source program (written in FORTRAN) and a number of data sets. The source program consists of the MAIN program along with certain subroutines and functions. The data sets are stored in the FORTRAN files, which are referred to within the source program by their numbers.

A simulation involves creating a load module from the source program and executing it using the data inputs in the FORTRAN file.

A detailed documentation of the REM model that describes the different capabilities of the model and enables users to use the model for various policy analysis purposes is available in mimeo form under the title "Documentation of the Regionalized Electricity Model" by Dilip P. Kamat, University of Texas at Austin, June 1976.

The original model was designed to be run in FORTRAN on an IBM 360. All the results documented in the original articles were obtained through this system. All recent work on the demand submodel has been done through TROLL, operating on the IBM VM/370, referred to as CMS (Conversational Monitor System).

Most of the data developed for the model are stored on magnetic tape. The demand data collection is stored in TROLL format, through the TROLL computer system of the Massachusetts Institute of Technology in both one- and two-dimensional data files.

The supply data collection and the financial submodel input parameters are stored on magnetic tape in FORTRAN compatible format. No technical tape descriptor is available, but the tapes can be read with CMS tape default values.

The transmission and distribution equipment data is not available at the M.I.T. Energy Laboratory, but a copy of the data is being used by researchers at the University of Austin, Texas.

A detailed description of the different data sources and a description of the input data for base case simulation are described in the Appendices of Electric Power in the U.S. by Martin Baughman, Paul Joskow, and Dilip Kamat.

1.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

REM is now being utilized by a number of researchers around the country.

Martin Zimmerman at MIT is incorporating specific regional coal supply functions into the model. Dale Jorgenson at Harvard is integrating the model with an aggregate model of the economy that will eventually capture important interrelationships between the electricity sector and the economy as a whole.

The ERDA Light Water Reactor (LWR) Program Strategy Analysis and Evaluation Project conducted by the Energy Laboratory at MIT has also applied the REM model framework to evaluate the technical advances in the construction and operation of LWRs in terms of their potential for decreasing construction and operating costs associated with delivering electricity.

The MIT model assessment group has compiled a list of potential policy applications, as shown in Table 3 (see page 30).

Martin Baughman and Dilip Kamat at the University of Texas are currently working with a modified version of the REM model.

Keith David Brown at The University of Texas, Austin, has come up with a monthly production simulator for the REM that presents a method of simulating the process of bulk power production that improves on the method used in the REM developed by M.L. Baughman and P.L. Joskow.

1.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the REM Project):

Baughman, M.L. and Joskow, P.L., "A Regionalized Electricity Model," MIT Energy Laboratory Report No. MIT-EL 75-005, Cambridge, MA., Dec. 1974.

This document reports on research in progress. In Chapter 1, the authors review the economic principles of electric utility behavior, both in the operations and planning spheres. In Chapter 2, the authors discuss how these principles have been combined into the specification and development of an engineering-econometric simulation model for electric utility behavior. Finally, in Chapter 3, the results of some sample simulations done with the substitution possibilities inherent in the model structure exemplify how it can be used. Since this is a report on work in progress, the simulations discussed are not to be reviewed as forecasts but rather as examples of model use.

Baughman, M.L. "Documentation and User's Manual for Interfuel Competition Model V.3 FORTRAN," Sept. 1973, mimeo.

The Interfuel Competition Model (V.3) is basically an engineering/economic simulation program for the medium to long-range (3-30 year) interactions of the major primary fuels and secondary energy sources (coal, oil, natural gas, nuclear fuels, and electricity) in the U.S. energy consuming markets. The purpose of the model is to match the consuming sector demands with the energy supplies in a way that is consistent with consumer preferences and relative fuel prices. The purpose of this document is to acquaint potential users and interested parties with some of the capabilities of this model.

Baughman, M.L. and Joskow, P.L., in association with F.S. Zerhoot, "Interfuel Substitution in the Consumption of Energy in the United States," MIT Energy Laboratory Report No. MIT-EL 76-002, Cambridge, MA., May 1974.

The effects of alternative public policies on the consumption and prices of various forms of energy in the United States depends critically on the nature of consumer demands for fuels and the supply characteristics of these fuels. Previous work on energy demand has tended to concentrate on the demand for particular fuel as determined by standard economic variables such as the price of the fuel, income levels, sometimes the price of alternative fuels, and other demographic characteristics of the consuming population. In this work the consumer decision-making process is viewed as being composed of two steps. First, the consumer decides that he wants a particular service and, second, seeks to find the fuel that will provide this service most cheaply. This view leads the authors to concentrate on substitution possibilities among fuels for particular services rather than own-price elasticities for a particular fuel.

This paper presents results for the determinants of energy consumption in the residential and commercial sector in the United States. First, a discussion of the conceptual model used for fuel choice decisions is presented. Then, empirical results are given for appliance choices in the residential sector for four selected appliances and for the "fuel-split" of aggregate energy consumption among the three fuels used in the residential and commercial sector. The own-price and cross-price elasticities are estimated and discussed.

Next, the paper discusses the determinants of total energy demand in the residential and commercial sector and presents empirical results for a simple flow adjustment model. The long-run price elasticity of total demand in this sector is estimated to be about -0.5, while the short-run (one-year) value is -0.15. Finally, the estimated relationships are used to make projections to 1980 for alternative price scenarios. These results show that significant consumption responses to changing fuel prices can be expected and, further, that some states are much more dramatically impacted than others.

Baughman, M.L. and Joskow, P.L., "Energy Consumption and Fuel Choice by Residential and Commercial Consumers in the United States," Energy Systems and Policy, Crane, Russak and Company, Inc., 1975.

The purpose of this paper is to report the conceptual design and estimation results of models for total demand and aggregate fuel choice decisions in the residential and commercial sectors. The authors started with the view that fuel utilization decisions can be separated into a two-level decision process. First, the consumer decides on the level of energy-using services he/she desires to meet his/her functional needs, then seeks to find the combination of fuels that will provide these services most cheaply. This dichotomy formed the basis for the models actually adopted.

The model used to explain total demand for energy in the residential and commercial sectors is a simple flow adjustment model. The long-run price and income elasticities of demand in this sector were estimated to be about -0.50 (after adjustments of fuel mix) and 0.6, respectively. The short-run (one-year) elasticities were about 16% of these values.

A set of simulations were performed using alternative scenarios about the evolution of future prices. The results show that much conservation can be expected to take place in the residential and commercial sectors as a result of past and expected future price increases. When comparing the model behavior with that used by the FEA in its Project Independence analyses, the differences indicated that the FEA overestimated future energy consumption trends for the residential and commercial sector. Also, in response to President Ford's proposed taxes on oil, the model exhibits little additional shift away from that fuel above that expected purely in response to the existing increase of oil prices to $11 per barrel.

Baughman, M.L. and Joskow, P.L., "The Effects of Fuel Prices on Residential Appliance Choice in the United States," Land Economics, February 1975.

In this paper the authors seek to estimate the effects of fuel prices on the fuel choice decisions by residential consumers for four important energy usage categories for which consumers face two or more fuel alternatives: space heating, water heating, cooking, and clothes drying. These usage categories account for approximately 80% of residential energy consumption in the United States. Explicit specifications and empirical results for the application of the logit model of fuel choice to the appliance decisions of residential consumers for four types of appliances are presented in this paper.

Kamat, D.P., "A Financial/Cost of Service Model for the Privately Owned Electric Utility Industry in the United States," Master of Science Thesis, Alfred P. Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA., June 1975.

In the recent past, electric utilities have faced serious financial problems. Operating and capital costs have been rising due to increased fuel costs, interest rates, and tightened environmental constraints. This has resulted in reduced profits for the utilities; hence, they are attracting less capital. Many solutions have been suggested to solve this problem of capital shortage, all of which have varied impacts on the future of electric utilities. The purpose of this thesis was to build a financial model that could analyze the effects of these policy changes suggested to relieve the capital shortage. This model was then hooked up with a regionalized electricity model at the Energy Laboratory, MIT, and it was possible to get elaborate scenario simulations of the electric utility industry for the various policy alternatives. The study concludes that many of the suggested changes, such as increased investment tax credits, are not as effective as publicized, whereas others, such as inclusion of construction work in progress in the rate base, have a major impact.

Joskow, P.L. and MacAvoy, P.W., "Regulation and the Financial Condition of the Electric Power Companies in the 1970s," American Economic Review, 65, May 1975.

The purpose of this paper is to assess the financial prospects of the nation's electric utility industry, given existing regulatory institutions and continued high rates of growth of demand in the late 1970s.

Bottaro, D.J. and Baughman, M.L., "Estimation of Transmission and Distribution Equipment Needs," MIT Energy Laboratory Working Paper, MIT-EL 75-001WP, Jan. 1975.

This paper is the first in a series estimating the capital equipment needs, capital costs, and operation and maintenance expenses of the transmission and distribution systems in the electric power sector.

Sequeira, S.G. and Baughman, M.L., "Engineering Estimates of Transmission and Distribution Equipment Costs," MIT Energy Laboratory Working Paper MIT-EL 75-002WP, Cambridge, MA., March 1975.

This paper is the second in a series estimating the capital equipment needs, capital costs, and operation and maintenance expenses of the transmission and distribution systems in the electric power sector. The paper reviews data on the costs of distribution transformers (for both overhead and underground systems), distribution substations, transmission and distribution lines, transmission substations, and the cost of metering systems, both for residential and large commercial and industrial consumers.

Baughman, M.L. and Bottaro, D.J., "Electric Power Transmission and Distribution Systems: Costs and Their Allocation," IEEE Transactions on Power Apparatus and Systems, P.A.S.-95, May/June 1976.

The costs derived from installing, operating, and maintaining the transmission and distribution system have historically comprised about 2/3 the total costs of producing and delivering electricity to residential/commercial customers, and over 1/3 the total costs of supplying electricity to large industrial customers. This paper estimates the cost of transmission and distribution for nine regions of the United States for the above two customer classes. These costs are detailed for six categories of equipment used in the transmission and distribution system and the contribution to the total cost of each equipment category is determined.

Joskow, P.L., "The Future of the U.S. Nuclear Energy Industry," Bell Journal of Economics and Management Science, Spring 1976.

This paper examines the demands for nuclear reactors, raw uranium, and fuel-cycle requirements by the U.S. electric utility industry over the next 20 years, under a number of different possible states of the world. The analysis is performed by using the MIT Regional Electricity Model (REM) developed by the authors. This model is an engineering-econometric-financial simulation model of the electric utility industry in the United States. It includes a supply submodel, a demand submodel, and a regulatory financial submodel. The analysis indicates that demands for reactors, raw uranium, and uranium enrichment, will be substantially below the projections made by such government agencies as the Atomic Energy Commission. These demands are shown to be very sensitive to the costs of air pollution control affecting coal utilization, the costs of uranium and uranium enrichment, the price of oil, and electric utility regulatory practices. It appears that in almost all cases existing-plus-planned expansion of government-owned enrichment facilities will be sufficient to meet domestic needs until the mid-1980s. However, the continued financial viability of the five reactor vendors serving the domestic market is doubtful. Two or three of these vendors will either have to drop out of the market or obtain increased nuclear steam supply system orders from foreign countries.

Joskow, P.L. and Rozanski, G., "Utilization by the Electric Utility Industry in the United States, 1975-1995," MIT Energy Laboratory Working Paper No. MIT-EL 76-006WP, May 1976.

In this paper the authors make use of the MIT Regionalized Electricity Model (REM) to examine the course of future electricity consumption and fuel utilization by the electric utility industry for the U.S. as a whole as well as for each of the nine census regions in the U.S.

Baughman, M.L., Joskow, P.L., and Kamat, D., Electric Power in the United States: Models and Policy Analysis, MIT Press, Cambridge, MA., 1979.

This book reports the results of several years of research aimed at the development and application of an engineering-economic model of the electric power industry in the United States. This model is known as the Regionalized Electricity Model (REM).

In this book the authors have attempted to do two things. First, they have presented a detailed discussion of the structure and behavior of the Regional Electricity Model (REM), a computer simulation model developed over the past few years to facilitate understanding the effects of a variety of public policies on the electric utility industry in the United States. Second, the model has been used to examine the likely effects of public policies that appear to have some prospect of being implemented in the next few years.

The REM Model reflects the authors' perceptions of the need for a computer-based simulation model of the electric power sector in the United States, to be used as an aid in formulating and evaluating alternative public policies as they affect the supply and demand for electricity.

Kamat, D.P., "A Documentation of the Regional Electricity Model," mimeo.

The purpose of this document is to acquaint potential users and other interested parties with the multifaceted capabilities of this model and enable them to use it for various policy analyses.

Joskow, P. and Mishkin, F., "Electric Utility Fuel Choice Behavior in the United States," International Economic Review, October 1977.

This paper attempts to depart from the traditional (differentiable aggregate production function) specification of electricity production, using instead conditional logit analysis. The fuel choice of an electric utility for a new fossil-fuel based, load steam-electric plant is analyzed to explicitly account for the discreteness of fuel-burning techniques available to the firm. For this purpose a probability model of the conditional logit form is specified and estimated using maximum likelihood techniques.

MIT Model Assessment Group. "Independent Assessment of Energy Policy Models: Two Case Studies," EPRI EA-1071, Final Report, MIT Energy Laboratory, Cambridge, MA., May 1979.

Energy policy models are playing an increasingly important and visible role in supporting both private and public energy policy research and decision making. As their importance has increased so too has the need for model review and assessment to assist in establishing model credibility for users and those affected by model-based policy research. Toward this end EPRI had sponsored the MIT Energy Laboratory in a one-year project to assess two important energy system models, the Baughman-Joskow Regionalized Electricity Model and the Wharton Annual Energy Model, and to identify and analyze organizational and procedural issues in the model assessment process.

Mostafa, M., "Regional Analysis of Transmission and Distribution Needs and Costs in the United States," Master of Science Thesis, Center for Energy Studies, The University of Texas at Austin.

Regression analysis is used to estimate equations for six major equipment items and the three types of operation and maintenance expenses for transmission and distribution of electricity. The United States is divided into nine census regions, and equations are estimated for a pooled national aggregate and each census region. A ten-year time series of cross-sectional data for privately owned utilities are used to perform the regressions using ordinary least-squares technique.

Also, a survey of the capital costs of the six equipment items, which contribute significantly to the total cost of transmission and distribution system, is presented.

Finally, the contribution of the cost of each transmission and distribution equipment item and the operation and maintenance expenses of these systems to the total cost of electricity for residential, small light and power, and large light and power customers are computed.

White, D.E., "Extensions and Revisions of the MIT Regional Electricity Model," MIT Energy Laboratory Working Paper MIT-EL 78-018WP, Cambridge, MA., July 1978.

This paper reviews some of the changes made in the MIT Regional Electricity Model (REM) from September 1976 to May 1978. These changes were made either to better evaluate some energy policy questions or to better represent energy sector behavior.

Brown, K.D., "Implementing a Monthly Production Simulator for the Regional Electricity Model," Working Paper, Center for Energy Studies, The University of Texas at Austin, June 1979.

This paper presents a method of simulating the process of bulk electric power production on a regional basis for the United States. This production simulation method is designed for implementation in the Baughman-Joskow Regionalized Electricity Model (REM) and improves on the method previously used in REM.

Improvements in the new production simulation model in comparision with the previous one include:

a. incorporation of 17 types of generation plants instead of 9;

b. simulation of production on a monthly basis, rather than annually;

c. scheduling plant capacity for maintenance on a levelized monthly basis, rather than assuming maintenance requirements are met during annual offpeak periods; and

d. modeling pumped storage generation for peak sharing, and pump-lack load for monthly off-peak demand.

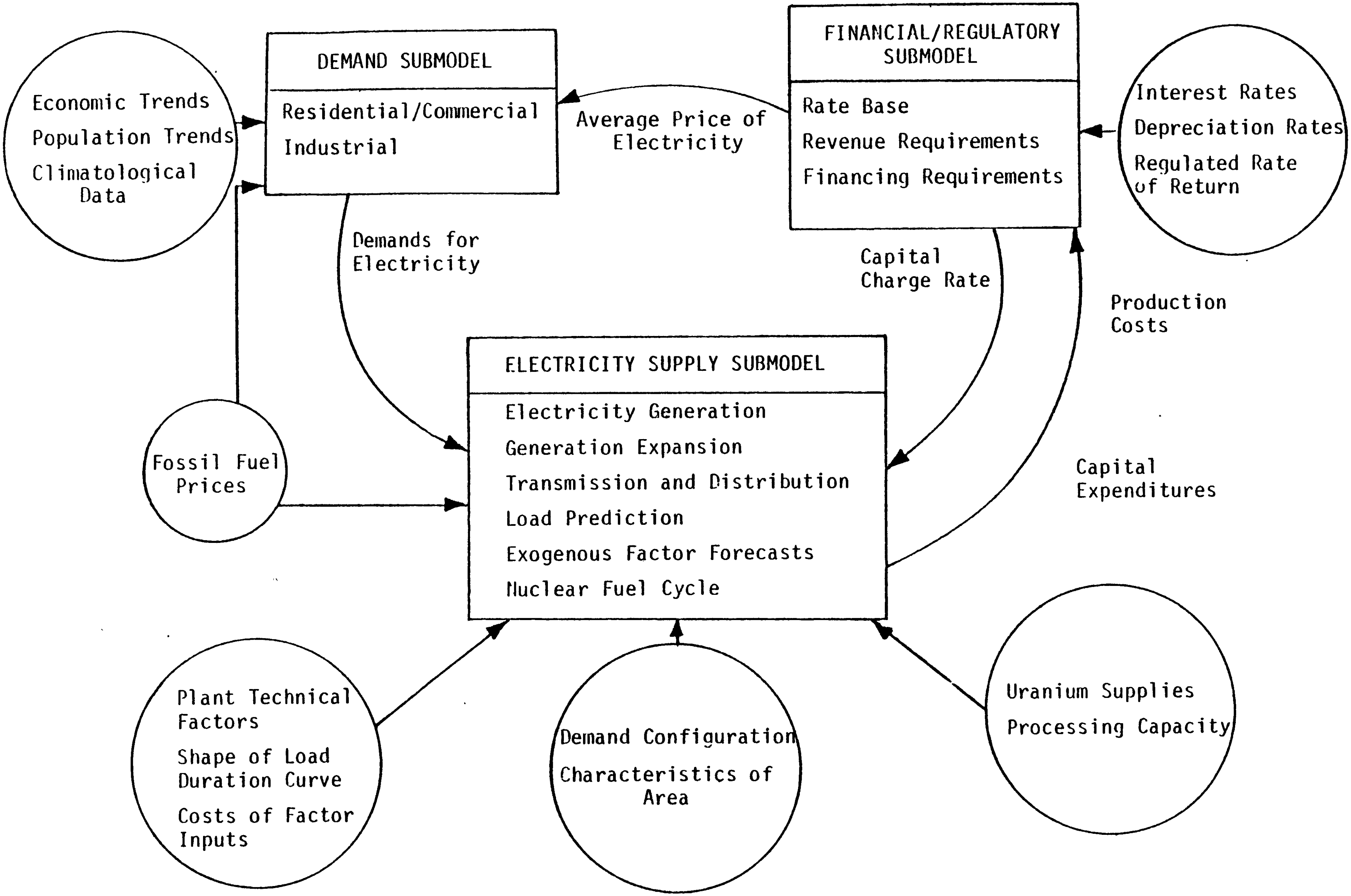

FIGURE 1. SCHEMATIC OVERVIEW OF THE STRUCTURE OF THE BAUGHMAN-JOSKOW MODEL

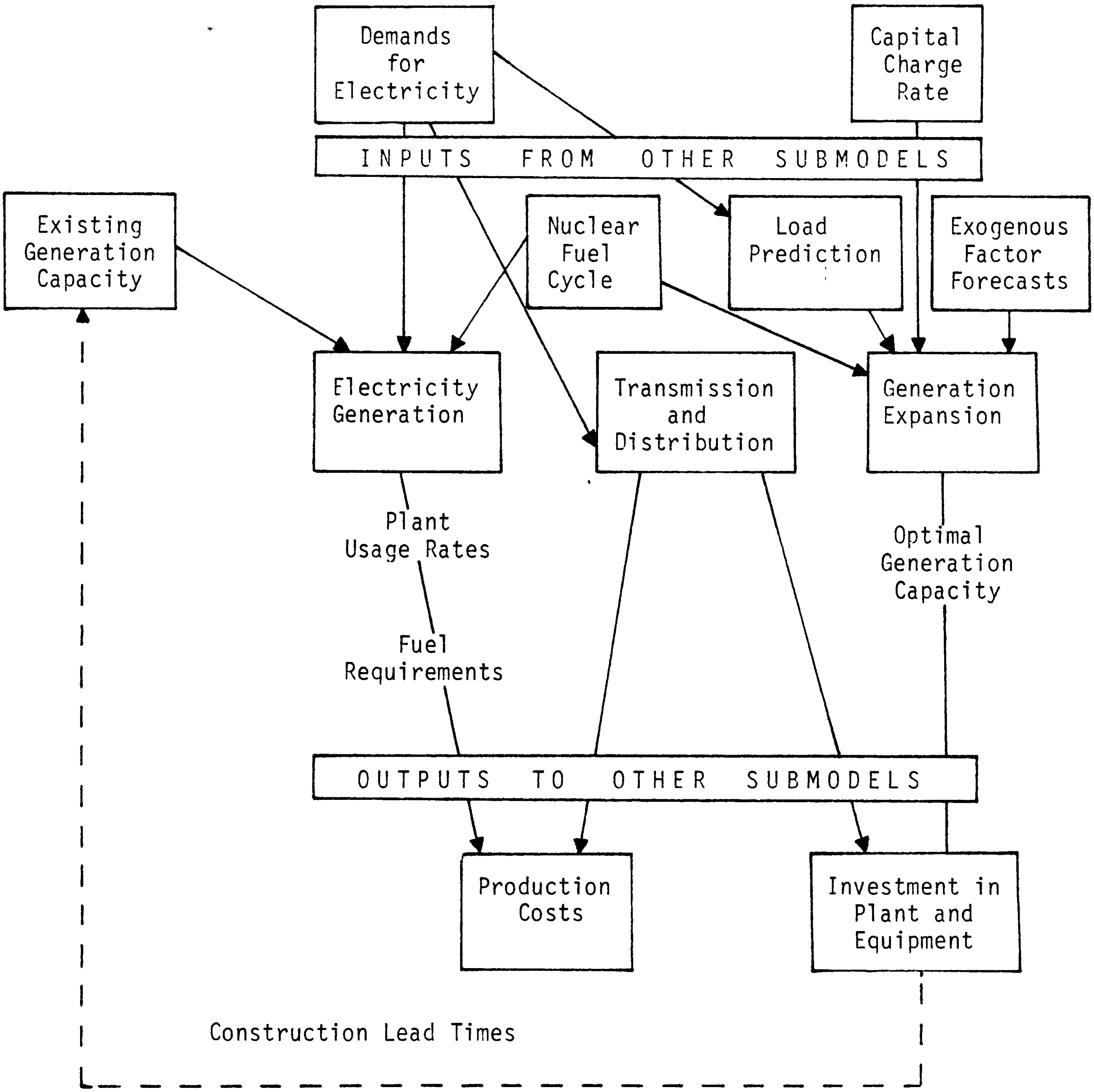

FIGURE 2. SCHEMATIC OUTLINE OF THE COMPONENTS OF THE REM SUPPLY SUBMODEL

$$\text{LOG}\left(\frac{\text{ENERGY}}{\text{POPULATION}}\right) = A + B * \left(\frac{\text{PERSONAL INCOME}}{\text{POPULATION}}\right) + C * (\text{MINIMUM TEMPERATURE})$$

$$+ D * \left(\frac{\text{POPULATION}}{\text{AREA}}\right) + E * (\text{AVERAGE PRICE}) + F * \text{LOG}\left(\frac{\text{ENERGY }(-1)}{\text{POPULATION }(-1)}\right)$$

RANGE = 1968 - 1972 $R^2 = 0.927$ F(5/239) = 622

COEF	VALUE	T-STAT
A	2.91	5.21
B	2.89e-5	1.77
C	-0.0012	-2.00
D	9.73e-6	2.34
E	-4.88e4	-3.83
F	0.839	26.4

$$\text{LOG}\left(\frac{\text{GAS}}{\text{ELECTRICITY}}\right) = A + C * \text{LOG}\left(\frac{\text{GAS PRICE}}{\text{ELECTRICITY PRICE}}\right)$$

$$+ D * (\text{MAXIMUM TEMPERATURE})$$

$$+ F * (\text{MINIMUM TEMPERATURE}) + H * \text{LOG}\left(\frac{\text{GAS}}{\text{ELECTRICITY }(-1)}\right)$$

$$\text{LOG}\left(\frac{\text{OIL}}{\text{ELECTRICITY}}\right) = B + C * \text{LOG}\left(\frac{\text{OIL PRICE}}{\text{ELECTRICITY PRICE}}\right)$$

$$+ E * (\text{MAXIMUM TEMPERATURE})$$

$$+ G * (\text{MINIMUM TEMPERATURE}) + H * \text{LOG}\left(\frac{\text{OIL }(-1)}{\text{ELECTRICITY }(-1)}\right)$$

RANGE = 1968 - 1972 $R^2 = 0.954$ F(7/482) = 1462

COEF	VALUE	T-STAT
A	0.07	0.56
B	0.208	1.65
C	-0.137	-3.29
D	-0.0015	-1.04
E	-0.0022	-1.58
F	-0.0022	-1.74
G	-0.0063	-3.19
H	0.897	66.0

TABLE 1. RESIDENTIAL AND COMMERCIAL DEMAND RELATIONSHIPS

$$\text{LOG (ENERGY)} = A + B * \text{LOG (AVERAGE PRICE)} + C * \text{LOG (VALUE ADDED)} + D * \text{LOG (PRICE OF CAPITAL SERVICES)}$$

RANGE = 1950 - 1972 $R^2 = 0.961$ F(3/19) = 182 D.W. = 1.86

COEF	VALUE	T-STAT
A	14.0	4.11
B	-0.239	-1.33
C	0.742	15.08
D	-0.270	-1.89

FIRST-ORDER AUTO CORRELATION COEFFICIENT = 0.337

$$\text{LOG}\left(\frac{\text{ENERGY IN STATE } i}{\text{ENERGY IN CALIF.}}\right) = A * \text{LOG}\left(\frac{\text{AVERAGE PRICE IN } i}{\text{AVERAGE PRICE IN CALIF.}}\right) + B * \text{LOG}\left(\frac{\text{POPULATION IN } i}{\text{POPULATION IN CALIF.}}\right) + C * \text{LOG}\left(\frac{\text{ENERGY (-1) IN } i}{\text{ENERGY (-1) IN CALIF.}}\right)$$

RANGE = 1968 - 1972 $R^2 = 0.984$ F92/237) = 7506

COEF	VALUE	T-STAT
A	-0.156	-4.92
B	-0.047	3.24
C	0.927	54.1

$$\text{LOG}\left(\frac{\text{GAS}}{\text{ELECTRICITY}}\right) = A + D * \text{LOG}\left(\frac{\text{GAS PRICE}}{\text{ELECTRICITY PRICE}}\right) + E * \text{LOG}\left(\frac{\text{GAS (-1)}}{\text{ELECTRICITY (-1)}}\right)$$

$$\text{LOG}\left(\frac{\text{OIL}}{\text{ELECTRICITY}}\right) = B + D * \text{LOG}\left(\frac{\text{OIL PRICE}}{\text{ELECTRICITY PRICE}}\right) + E * \text{LOG}\left(\frac{\text{OIL (-1)}}{\text{ELECTRICITY (-1)}}\right)$$

$$\text{LOG}\left(\frac{\text{COAL}}{\text{ELECTRICITY}}\right) = C + D * \text{LOG}\left(\frac{\text{COAL PRICE}}{\text{ELECTRICITY PRICE}}\right) + E * \text{LOG}\left(\frac{\text{COAL (-1)}}{\text{ELECTRICITY (-1)}}\right)$$

RANGE = 1968 - 1972 $R^2 = 0.945$ F(4/730) = 3.30

COEF	VALUE	T-STAT
A	-0.231	-4.31
B	-0.354	-6.80
C	-0.540	-8.23
D	-0.301	-7.13
E	0.856	58.9

TABLE 2. INDUSTRIAL DEMAND RELATIONSHIPS

Table 3: Potential Policy Applications

1. Changes in factors affecting electricity demand growth paths
   - economic/demographic trends
   - conservation policies

2. Load management
   - peak-load pricing*
   - cogeneration
   - seasonal pricing

3. Impacts of changes in cost factors
   - capital costs for new plants
   - fuel prices*
   - wage rates
   - taxes (possibly a Btu tax)

4. Changes in resource supply conditions
   - resource constraints*
   - increasing cost supply schedules

5. Costs of financing*

6. Industry responses to capital "shortage"
   - state financing*
   - less capital-intensive technologies
   - reduce growth
   - reduction in plant reserve margin

7. Regulatory policies
   - regulated rate of return*
   - inclusion of work in progress in rate base*
   - exclusion of noneconomic plants from rate base*
   - regulatory lag

8. Alternative lead times for capacity expansion*

9. Environmental constraints
   - siting restrictions
   - capital equipment requirements*
   - increased operating costs*

10. Technology assessment
    - advanced generation technologies: centralized and distributed
      conventional and nonconventional
      cogeneration fuel conversion
    - nuclear: non-LWR, breeder, etc.
    - storage
    - T and D

2.1 MODEL HISTORY

a.	Name:	An Econometric Policy Model of Natural Gas
b.	Developers:	Paul W. MacAvoy, Department of Economics, Massachusetts Institute of Technology, Cambridge, Massachusetts; currently at Yale University, New Haven, Connecticut Robert S. Pindyck, Sloan School of Managment, Massachusetts Institute of Technology, Cambridge, Massachusetts
c.	Duration:	1972 to 1974 1977 to 1978
d.	Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e.	Sponsor:	National Science Foundation

1.2 MODEL DESCRIPTION

a. Summary

The economic model of natural gas markets with explicit policy controls is built and simulated to predict and analyze the effects of alternative regulatory policies. The model consists of a set of econometric relations among several policy-related variables. It provides a vehicle for performing simulations into the future using different policy options, so as to indicate the effects of the options on the levels of prices and the size of the shortages. Thus, its formulation stresses price, reserve quantities, production quantities, and associated demands for production.

The econometric model has the important characteristics of:

a. simultaneously describing the behavior of both reserves and production markets;

b. describing the regional organization of the industry at a disaggregated level; and

c. accounting for the time-dynamics inherent in the various activities of the industry.

The natural gas industry is viewed as a complete system. Most previous econometric studies of natural gas (e.g., Balestra) have investigated either supply or demand but have neglected the simultaneous interactions of the two. The present model accounts for the simultaneous interaction of output and demand of both field and wholesale levels of the industry.

Regulation has been in effect for both field sales and transportation of gas. Consequently two distinct sets of markets are accounted for in modeling the gas industry. Production and demand are described in both the market for reserve additions and the market for wholesale deliveries. These markets are regional in nature; reserve additions are contracted for in regional field markets and gas production is delivered by pipelines to regional wholesale markets. These regional markets are interconnected through the network of natural gas pipelines across the country. The spatial organizations of these markets have been accounted for in the model.

The time dynamics of different stages of reserve accumulation, production, and demand are an important aspect of the model. Attempts have therefore been made to include appropriate time lags in all the relationships in the model.

A simplified diagram of the econometric model is shown in Figure 1 (see page 38) and a block diagram of the model is presented in Figure 2 (see page 39). The block diagram provides an overview of both the model's organization and the relationship between field and wholesale markets.

This block diagram provides a good starting point for understanding the model's structure.

The producer, in the gas and oil reserves market, engaged in exploratory activity has, at any point in time, a portfolio of drilling options available on both extensive and intensive margins. In deciding whether or not to drill, producers make a trade-off between expected risk and expected return, and thereby decide whether additional drilling will be extensive or intensive. This choice is influenced by changes (or expected changes) in economic variables such as field prices of oil and gas and drilling costs. The model developed here has an equation for wells drilled that is based on a rational pattern of producers' responses to economic incentives in forming their portfolios of intensive and extensive drilling. Drilling alone does not establish discoveries in the model. Equations are specified to determine the fractions of wells drilled that will be successful in finding gas, and the fraction successful in finding oil. The "success" ratios depend on whether economic incentives (e.g., price increases) result in drilling on the extensive or intensive margin (and this must be determined empirically). Two equations determine the size of discovery per successful well for gas and oil respectively. Discovery size is related to the number of successful wells drilled previously and to the volume of previous discoveries in that region, as well as to gas and oil prices.

Finally, the model generates forecasts of new discoveries from this set of equations. Total new discoveries (calculated for gas and oil) separately are the product of number of wells, success ratio, and size of find per successful well. This level of detail permits explicit consideration of the process of long-term geological depletion as well as the role of risk in determining the amount of exploratory activity.

Addition to reserves also occurs as a result of extensions and revisions of existing reserves. These extensions and revisions for both gas and oil depend on (1) price incentives; (2) past discoveries of gas and oil; (3) existing reserve levels for both gas and oil; and (4) the cumulative effect of past drilling.

Thus, additions to gas reserves are the sum of new discoveries, extensions, and revisions. Aside from changes in underground storage, subtraction from gas reserves occurs as a result of production. Similarly, additions to oil reserves are the sum of new discoveries of oil, extensions, and revisions. Since the model does not explain the production of oil from reserves, year-end oil reserves are not determined. These partly engineering, partly economic equations determine addition to reserves made by petroleum companies.

The level of natural gas production out of reserves depends not only on the size of the reserve base, but also on prices that buyers are willing to pay. The formulation of production supply in this model has the marginal cost of developing existing reserves determine a particular level of annual flow. Marginal production costs are dependent on reserve levels relative to production, so as the reserve-to-production ratio becomes smaller, marginal costs rise sharply. Thus, as can be seen in the block diagram, the level of gas production out of reserves is a function of both the field price of gas and quantity of year-end reserves in any one production district.

The <u>wholesale demand</u> for natural gas production is a function not of the <u>wellhead price of g</u>as but rather of the wholesale price. Average wholesale prices for gas are computed in the model for each consumption region in the country through a series of pipeline price markup equations. The price markups are based on operating costs, capital costs, and regulated rates of profit for the pipeline companies.

Of course, wholesale gas prices are not the only determinants of wholesale gas demand. Residential and commercial demand, and industrial demand, depend as well on the prices of alternative fuels (including the wholesale prices of oil) and "market-size" variables such as population, income, and investment, which help determine the number of potential consumers. Separate residential-commercial and industrial equations are formulated for each of five regions of the country. A third category of natural gas demand formulated within the model is the demand for gas as field extraction fuel.

Natural gas is competitive with fuel oil both in industrial and residential/commercial markets. The model therefore contains a set of wholesale demand equations for fuel oil. The fuel oil demand equations have the same structural form as do the natural gas demand equations, thus making it possible to compare changes in oil and gas demand in a consistent manner. As can be seen from the block diagram, these demands for oil depend on the wholesale prices for both oil and natural gas, and also on the same "market size" variables as gas demand.

The determination of natural gas production at the wellhead and, concurrently, the volumes delivered to buyers in wholesale markets, is accomplished in the model by an input-output table connecting production districts with consuming regions. A flow network is constructed, based on the relative flows calculated from 1971 data, and determines where each consuming region obtains its gas. This volume network also determines the pipeline price markups for gas, since those markups are functions of the volumetric capacities of the pipelines as well as mileages that gas must be transported across the country.

Once the model has been spatially closed, wholesale deliveries can be determined and summed to produce total deliveries for each region of the country. Then, given the forecasted demands from the wholesale demand equations, excess demand can be forecasted on a regional basis.

The model is estimated using pooled cross-section and time-series data. The time bounds and regional groupings are different for different equations. The model of natural gas is "almost" block recursive in nature. The estimated equations are used in the final form of the model and along with their estimation method are summarized on a block-by-block basis in Table 1 (see page 41). This set of equations is specified and estimated independent of each other. Taken one at a time, these equations are of limited use for forecasting the behavior of the gas industry. For analyzing the industry as a whole, the simultaneous interaction of both supply and demand on both field and wholesale levels is taken into account. This is done by simulating the model as a whole, i.e., by solving as a simultaneous system the set of equations that comprise the model. Simulations are performed that relate to both the past and future behavior of the natural gas industry. The first set of historical simulations performed over the period 1965-1971 provides a measure of model validation. The second set of model simulations through the year 1980 is used for forecasting and policy analysis.

The possibilities of stronger control or decontrol are investigated by introducing the proposed policy changes into the econometric model of gas field and wholesale markets. Assuming certain rates of growth of production costs, of economy-wide determinants of demand, and of oil prices, the econometric framework leads to additions to reserves and production from each of the production districts. There are also predictions from the model for residential and industrial demands for the different regions of the country. By inserting new modules for production, and by marking up field prices through roll-in pricing procedures in the modules for demand, predictions of reserves, production, and demands are made for each policy. Thus, a policy can be examined in terms of its pricing schedule for levels of production shortage.

Extensive forecasts of the size and location of these shortages through 1980 are reported in the book, The Economics of the Natural Gas Shortage (1960-1980) by P.W. McAvoy and R.S. Pindyck, Amsterdam: North Holland Publishing Company, 1975. However, certain policy changes rendered them somewhat dated, and new forecasts were therefore made to incorporate these policy changes. These are reported in the book, Price

Controls and the Natural Gas Shortage, May 1975. Also, new forecasts of a critical variable "outside" the model--the size of undiscovered gas reserves--was incorporated by inserting the new estimates into the equation sets and forecasting policy effects therefrom. All these changes showed that the gas shortage would be more extensive than forecast in the North-Holland book, and solving the shortage would require more new policies than previously expected.

The above version of the model was constructed from data through 1972. Although this version provides a satisfactory overall description of the industry, it did have some shortcomings. First, some of the equations, particularly several of those describing the process of exploration and reserve accumulation, fit the data poorly. Second, forecasts of the model seemed to be unreasonably optimistic in their implications for the kinds of price increases that would be needed to clear markets and clear excess demand for natural gas. In particular, the model predicted increases in onshore new discoveries and in offshore production in response to higher prices that were considerably out of line with engineering and intuitive estimates.

These problems were in large part a result of the limited range of data used in estimation. There may also have been problems with the specification of some of the model's equations. Because of these problems Professor Robert S. Pindyck constructed a new version of the natural gas model.[1] Estimation of this version was done from a data base updated through the year 1974 and for which errors in earlier data had been corrected. The structure of the revised model is also different in a number of respects, although the equations describing new discoveries of natural gas retain their original basic structure. Variables that describe the mean and variance of expected returns from exploratory effort have been simplified and revised, and alternative expressions describing price expectations have been introduced. The portion of the model describing extensions and revisions of natural gas and oil reserves was enlarged, so those variables are now described in more detail (and their behavior can be simulated much more accurately). In addition to reestimating equations for production out of reserves with more extensive data, reserve production ratios are constrained during simulations of the model to remain above minimum feasible values. Finally, equations for natural gas demands were reestimated using real, rather than nominal, prices and incomes. The new version of the natural gas model is depicted in a block diagram in Figure 3 (see page 40), which for simplicity ignores the regional structure.

The estimation of the revised model was done by using the same method that was applied to the earlier version: a generalized least-squares procedure that accounts for cross-sectional heteroskedasticity and autocorrelation of the error terms across time. An historical simulation

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1) The first version of the model is described in McAvoy and Pindyck (1972); Version 2 is described in McAvoy and Pindyck (1973); and Version 3 is described in detail in McAvoy and Pindyck (1975a, 1975b). The new version of the natural gas model is known as Version 4 and is described in Pindyck, R.S. (1978).

comparison of the two models is summarized in Table 2 (see page 42), where mean and root mean square (rms) simulation errors are presented for the important endogenous variables. The revised model has also been used to examine alternative Federal Price Commission (FPC) price policies.

The revised version of the natural gas industry recommended that increases in the field price of natural gas are needed to avert growing shortages, and indicates that larger increases are needed than those indicated by the earlier model. The revised model differs from its predecessor largely in its supply response, and this is partly the result of a respecification of some of the supply equations and partly of the reestimation with more recent data. The policy implications of the revised model are supportive of the FPC's new proposed area rates, and it would appear that these new rates will go a long way toward clearing natural gas markets during this decade.

Although the revised model provides an improved description of the natural gas industry, it is still lacking in its representation of exploration and discovery of new gas and oil reserves. The economic relationships that one would expect to hold on the micro level are not supported by the data in new discovery equations, and those equations do not fully capture the geological determinants of the distribution of discoveries. This is partly the result of the level of regional aggregation used in estimating the model, and it may be more fruitful to model exploration and discovery at the micro level of individual pools and fields. Future work in this direction might help in a better understanding of the dynamic response of exploration and discovery to the higher energy price.

b. Data Base

The data collection that supports the Natural Gas Model consists of data series for the U.S. lower 48 states for supply by production region (i.e., districts) and demand regions (states). The data are primarily from public sources, and are described in detail along with the computerized storage below.

Supply

Wells

Data on wells were obtained from the Joint Association Survey of Drilling Statistics and World Oil magazine for FPC production districts. The data is in singular units, for the range of years 1963-1972, except for offshore and wildcat wells, which are available from 1958 to 1974. The following are the production districts:

Production Districts

California
Colorado/Utah
Kansas
Louisiana North
Lousiana South Onshore
Lousiana South Onshore & Off
Mississippi
New Mexico North
Permian
Texas 1
Texas 2
Texas 3
Texas 4
Texas 6
Texas 9
Texas 10
West Virginia
Kentucky
Wyoming

Exploratory Wells

Data on total exploratory wells, as well as on the number of successful gas and oil wells, were collected from the same sources. From these time series several additional time series were constructed: the ratio of successful gas wells to successful oil wells, the ratio of successful gas to total exploratory wells, and the cumulative number of exploratory wells.

Wildcats

Wildcat wells are a class of exploratory wells, but the definition excludes extension wells. The range of years for wildcats is 1958-1972, obtained from issues of World Oil magazine, for offshore Louisiana only.

Other Offshore Wells

Development and extension exploratory wells (excluding wildcats) for offshore Louisiana were obtained from World Oil magazine for 1958-1974. The number of drilling rigs was also obtained.

Offshore Acreage

Offshore Lousiana acreage data were obtained for the years 1958-1972 from the U.S. Department of the Interior's Outer Continental Shelf Statistics. Several categories of data are available.

Total acreage under supervision, producing and non-producing acreage, and acreage leased were collected. These were used to construct time series for new producing acreage, acreage forfeited, and cumulative number of acres leased.

Reserves

The reserves of natural gas data, (and oil, whenever available) were obtained for the most part from the publication Resources of Crude Oil, Natural Gas Liquids, and Natural Gas from the American Gas Association/American Petroleum Institute/Canadian Petroleum Association, for the years 1964-1974, except for offshore, where the range of years is 1958-1974. The units are millions of cubic feet (mcf) for gas, or thousand barrels for oil.

Discoveries, Revisions, Extensions

For both natural gas and oil, total new discoveries, total revisions, and total extensions were collected. Year-end reserves of gas and oil were also collected. Units are millions of cubic feet for gas, and thousand barrels for oil.

Average Size

The time series on number of successful wells and total new discoveries, for both gas and oil, were used to construct a time series for average size of discoveries. Fitted values were obtained from the estimated size of discovery equations, and estimates of variance overtime.

Potential Gas Reserves

Potential gas reserves for each district were obtained from the publication Potential Supply of Natural Gas in the U.S., Mineral Resources Institute, 1971, estimated as of 1963. An estimate of the original oil in place was also obtained.

Production

Production data were obtained from the publication Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas from AGA/API/CPA for years 1961-1974, except for offshore Louisiana, where the range of years available is 1955-1974. Total production of natural gas and oil were collected, and a series on cumulative production of each was created.

Depletion Index

An index of depletion of natural gas and oil in each production district was constructed using data from the production and from the reserves sections. The depletion index is defined as: ((total potential reserves -- year-end reserves -- cumulative production)/total potential reserves).

Demand

The demand data were obtained for 40 demand regions (corresponding to the lower 48 states, New England comprising one region, Maryland, Delaware and D.C. comprising another), in units of million cubic feet or thousand barrels.

Sales

Sales by Interstate Pipeline Companies

Industrial sales of natural gas and retail sales to communities by interstate natural gas pipeline companies were obtained from FPC Annual Form 2 Reports. Total sales of gas for resale were also obtained from the FPC Form 2 Reports. The category "sales for resale" indicates resales to intrastate distributors only.

Intrastate Sales

Total intrastate sales were determined from total state gas production from *Reserves of Crude Oil, Natural Gas Liquids and Natural Gas* (AGA/API/CPA) and subtracting sales to interstate pipeline companies by producers, which is available from the FPC's *Sales by Producers of Natural Gas to Interstate Pipeline Companies*.

Lease and Plant Fuel Sales

The time series for lease and plant fuel sales was obtained from the Bureau of Mines, *Minerals Yearbook*.

Residential/Commercial and Industrial Consumption

To allocate total sales to the appropriate sectors, a ratio of both industrial and residential/commercial consumption to total consumption first was obtained with data from the Bureau of Mines, *Minerals Yearbook*. This ratio was then used to determine the proportion of total sales to allocate to the sector where total sales equals: interstate sales to the industrial and residential/commercial sectors, plus total intrastate sales, plus total sales for resale (all series described above).

Oil Quantities

Oil quantities sold to the residential/commercial sector were obtained from the API's *Petroleum Facts & Figures* series on "Sales of Heating Oil, Grade No. 2, by States." Oil sold to industry was obtained from the API's "Total Sales of Residual Fuel Oils by States." Total sales refers to all uses of residual fuel oil.

Prices and Economic Indicators

Prices for gas, oil, and alternative fuels were obtained in addition to some economic indicators. The time series are described below.

Fuel Prices

Wellhead and Contract Prices for Natural Gas

Data on contract price at the wellhead were obtained in units of U.S. cents/MCF for the years 1952-1974 by 28 production districts. The data were originally compiled by Foster Associates.

The FPC's publication, Sales of Natural Gas, was used to obtain average wellhead prices in U.S. cents/MCF, for the years 1962-1974, for 18 FPC producing districts. A wellhead price for the eight producing regions of the model was required, and a weighted average for each of the eight regions was computed using the FPC districts' consumption as weights.

The average price of gas at the wellhead for offshore Louisiana, in dollars/MCF, for the years 1955-1974, was obtained from the publication Outer Continental Shelf Statistics, of the U.S. Department of the Interior.

Wholesale Natural Gas Prices

Average wholesale prices of intrastate, interstate, and main-line sales were collected. All units are dollars/MCF and the range of years is 1962-1974. These prices are from FPC Form 2 Reports. A wholesale price of gas was then calculated using these price series and the quantities to compute a weighted average price.

Oil and Other Alternative Fuel Prices

There are several price series for oil: the wellhead price, on and offshore, an industrial price, and a wholesale price of number 2 fuel oil. The wellhead price for onshore oil in dollars/barrel is from the Bureau of Mines' Minerals Year: for years 1954-1974 in dollars/barrels from Outer Continental Shelf.

The average wholesale price of number 2 fuel oil in cents per gallon for 1960-1972 was obtained from two sources, Fuel Oil and Heat and Platt's Oil Price Handbook and Oilmanac. Where the two sources were not in agreement, an average of the two was used. For states where prices for more than one city was cited, a weighted average was computed using population size as weights. For eleven states, no price was quoted in either source. In these cases, prices from adjacent states were used, with no adjustment. The eleven were considered to be nominal consumers of fuel oil.

The price series used for the industrial price of fuel oil was obtained from the Edison Electric Institutes' Statistical Annual of the Electric Utility Industry. The price paid by electric power companies for the years 1954-1972 in dollars/Mcf energy equivalent of natural gas was used.

The wholesale price series for coal was obtained from the same source as oil, above, and from the same category. A weighted average price of "alternative fuels" was then computed from these two series, using kilowatt hours generated by each fuel as weights.

Economic Indicators

Two interest rates, the BAA for 1946-1973 from the National Bureau of Economic Research data base, and the AAA bond rate from the Federal Reserve Bulletin, were collected.

Manufacturing sector indicators obtained are: value-added and new capital expenditure, in millions of current dollars, from the *Annual Survey of Manufacturers*, for 1958-1971, and value of *construction contracts, from 1956-1971*, in millions of current dollars from two sources: *Statistical Abstract of the U.S.* and *Dodge Construction Contract Statistics Service.*

Personal income and population were also collected -- personal income in millions of current dollars, from 1956-1972, population in thousands, for 1955-1972. The sources are the *Survey of Current Business* and *Current Population Reports*, respectively.

Miscellaneous: Costs, Pipelines, and the Herfindahl Index

An index of drilling costs, for exploratory drilling/well, by 18 FPC production districts, was obtained from AGA/API/CPA's *Joint Association Survey*. The index is an average for the time period 1963-1972.

Pipeline volumetric capacity, as a proxy for flow data that was not available to the researchers, was used as the capacity variable. For net exporting states, pipelines flowing out of the states were included in the calculation, which was the sum of the squares of the pipeline diameters. The diameters of the pipelines were obtained from a 1968 FPC pipeline map. The pipeline map was also used to compute a weighted average distance from producing to consuming regions.

The Herfindahl index was constructed with data from FPC Form 2 Reports. The fraction of gas consumed in region j, provided by company i, or X_{ij}, was obtained from the FPC. The index is defined as:

$$H_j = \quad X_{ij}^2.$$

The index was computed for each state, each year, and the mean value for each state was then used.

c. Computer Aspects

The computational work was performed at the Computer Research Center of the National Bureau of Economic Research (NBER) in Cambridge, Massachusetts, using the TROLL system for the estimation and simulation of the model. The data base was also constructed and maintained at the NBER Computer Research Center.

The programming code for the simulation model consists of 1266 equations, which are generally block recursive and are solved for each year of the forecast period. Because of the model's large size, 512 K bytes of core are required for simulation.

The model and its related data are currently stored on tape through the TROLL computer system of the Massachusetts Institute of Technology. A TROLL account is needed to read a TROLL tape. TROLL stores data in one- or two-dimensional data files and both forms are used. There are no comments associated with the data files and the mnemonics used in the publications are not those used for the data files or the equations.

2.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The model can be applied to different forecasting and policy analysis problems. As an example, the econometric model has been used by the authors to determine the demand function for liquefied natural gas (or another substitute for natural gas) in different regions of the country under one or another particular field price regulatory policies.

There are other interesting applications. For example, it is straightforward to use the model to measure gains and losses that would result from federal allocation policies that shift gas from one region of the country to another. Another application example would be to measure gains and losses resulting from the regulation of intrastate gas so as to make its price always equal to the interstate price. Such a policy would change the allocation of supplies and would also affect the levels of supply and demand, and the extent of the impact could be measured using the model.

The revised version of the model has been used to project the effects through 1985 of three alternative natural gas policies: a continuation of current FDC national area rates, President Carter's proposed plan to increase new contract wellhead prices of "new" gas and tax industrial consumers of gas, and a plan of phased deregulation in which new contract-prices would be raised in incremental steps toward their free market level. The results suggest the urgency of fundamental reform of natural gas pricing policies.

2.4 LIST OF WORKING PAPERS, ARTICLES AND BOOKS (generated by the modeling):

MacAvoy, P.W. and Pindyck, R.S., "An Econometric Policy Model of Natural Gas," Working Paper No. 635-72, Massachusetts Institute of Technology, Sloan School of Management, Cambridge, Massachusetts, 1972.

This paper describes the first version of the econometric model of natural gas.

MacAvoy, P.W. and Pindyck, R.S., "Alternative Regulatory Policies for Dealing with the Natural Gas Shortage," The Bell Journal of Economics and Managment Science, Vol. 4, no. 2, Autumn, 1973.

Low wellhead ceiling prices over the past decade have led to the beginning of a shortage in natural gas production. If the demand for gas grows as expected during the 1970s, and if ceiling prices remain low as a result of restrictive regulatory policy, this shortage could grow significantly. This paper examines the effects of this and alternative regulatory policies on gas reserves, production supply, production demand, and prices over the remainder of this decade. An econometric model (Version 2) is developed to explain the gas discovery process, reserve accumulation, production out of reserves, pipeline price markup, and wholesale demand for production on a disaggregated basis. By simulating this model under alternative policy assumptions, the authors find that the gas shortage can be ameliorated (and after four or five years eliminated) through phased deregulation of wellhead sales, or through new regulatory rulings, either of which imply moderate increases in the wellhead price for new contracts. These results are also rather insensitive to alternative forecasts of such exogenous variables as GNP growth, population growth, and changes in the prices of alternate fuels.

MacAvoy, P.W. and Pindyck, R.S., The Economics of the Natural Gas Shortage (1960-1980), North-Holland Publishing Company, Amsterdam, 1975.

This book reports the study made by the authors, appraising the natural gas shortage and evaluating ways to reduce the shortage based on a large-scale econometric policy model of natural gas (Version 3). The approach followed in the book divides the institutional and analytical materials into two parts. First, the political and institutional frame of reference is described, the natural gas shortage is estimated, and forecasts are made of the effects on this shortage of various alternative policies. Second, a large-scale econometric policy model of natural gas markets--both field markets and wholesale distribution markets--is presented in detail. This is done so noneconometricians can deal with results from the policy analyses, leaving it to the more technically-oriented analyst to check these results against the model and simulation descriptions.

MacAvoy, P.W. and Pindyck, R.S., "Price Controls and the Natural Gas Shortage," National Energy Project, May 1975.

This book traces the effects of the natural gas shortage of the early 1970s through the various markets and geographical regions in which gas is bought and sold. The authors find that consumers in the Northeast, North Central, and Western regions of the United States have had to shoulder a larger share of the shortage burden than consumers in the Southeast and South Central regions. They also find that future gas shortages will be more severe than previously forecast.

On the basis of these and other findings, MacAvoy and Pindyck evaluate four proposals for alleviating the gas shortage, concluding that phased decontrol of the natural gas industry would best serve the interest of consumers as a group. Without such a policy, they find, the shortage will grow worse, with the large population and industrial centers of the Northeast and North Central regions continuing to bear more than their share of hardship.

The findings presented in this study result from the authors' latest forecasts of U.S. natural gas production and consumption under different assumptions about U.S. government energy-related policies. This work builds on the authors' earlier modeling efforts, incorporating much new information. The econometric model used is described in an appendix.

Lloyd, K.R., "A User's Guide to the MIT Natural Gas Model," MIT Energy Laboratory Report No. MIT-EL 75-011, June 1975.

This User's Guide provides information on how to run the model on TROLL. Policy and parameter inputs that allow the user to specify a precise set of economic and regulatory conditions are described. A TROLL program, written by the modelers, is described. It allows maximum flexibility of user interaction and eliminates the need for extensive knowledge of TROLL. There is also a step-by-step description of the procedure to run the model for those acquainted with TROLL.

Pindyck, R.S., "Higher Energy Prices and the Supply of Natural Gas," Energy Systems and Policy, Volume 2, Number 2, 1978.

This paper describes a new version of an econometric policy model (Version 4) of the natural gas industry. Differences between the model and the predecessor are examined in the context of recent data for gas and oil prices, exploratory activity, reserve additions, and production. The model is used to forecast the regional effects on the industry of the higher prices recently proposed by the Federal Power Commission.

Pindyck, R.S. ,"Prices and Shortages: Policy Options for the Natural Gas Industry," Options for U.S. Energy Policy, 1977.

In this paper, the revised version of the Natural Gas Model is used to forecast the effect of alternative price policies. FPC area rates, the Carter Plan, and Phased Deregulation Shortages have been projected under alternative policies. The costs of the shortages have been calculated in terms of lost consumer surplus, lost GNP, and induced expenditures for oil and coal.

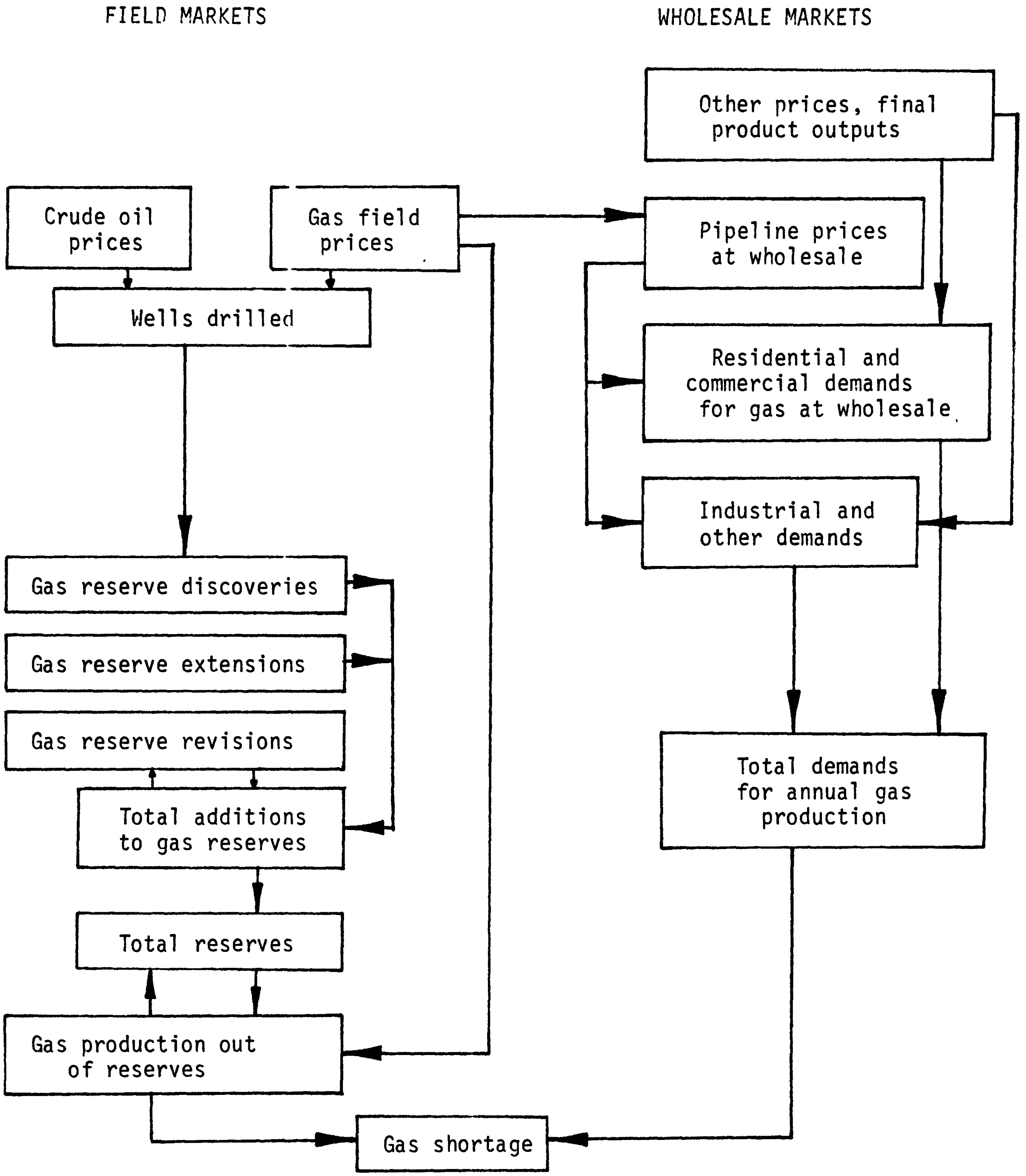

FIGURE 1. SIMPLIFIED ECONOMIC MODEL FOR THE NATURAL GAS INDUSTRY

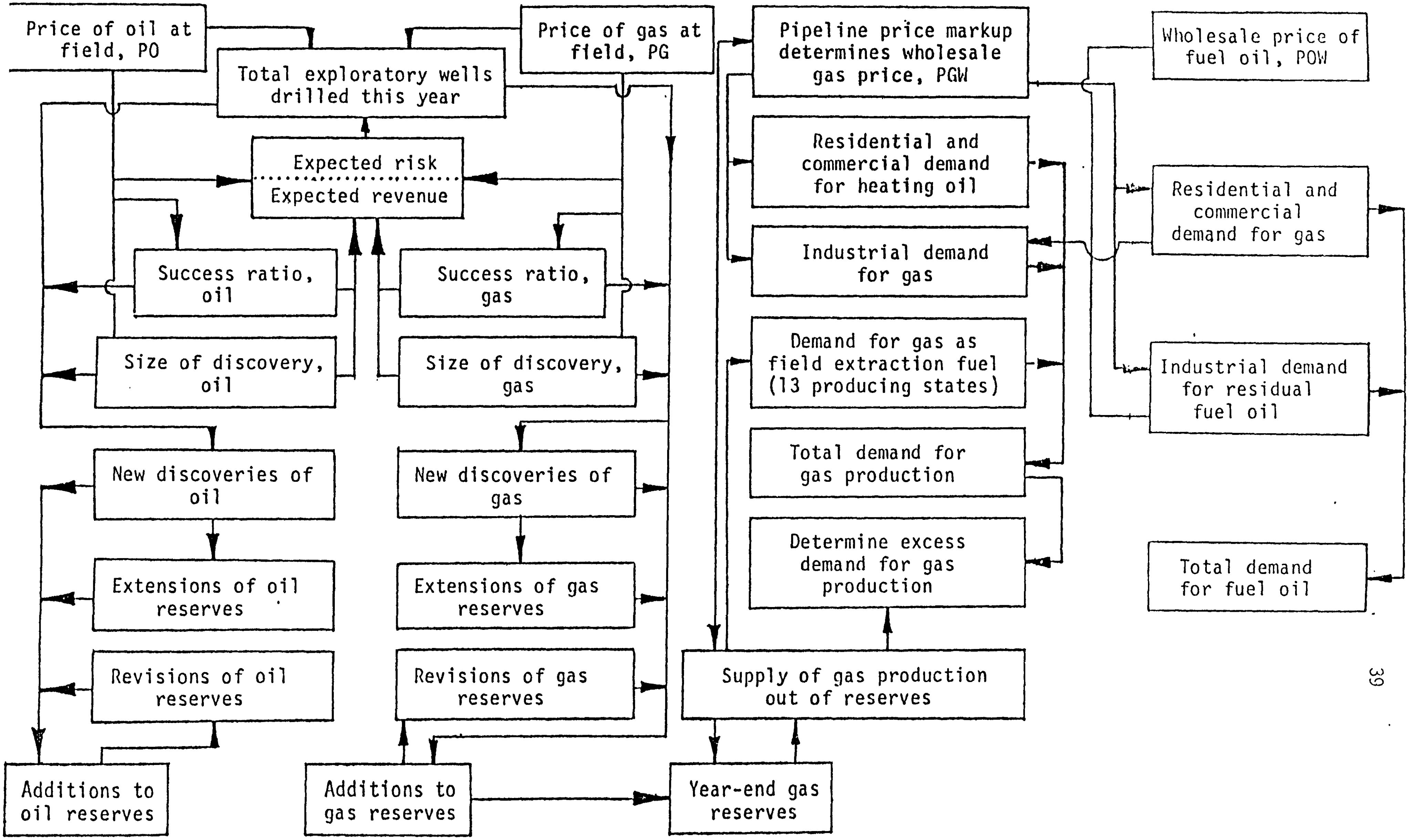

FIGURE 2. BLOCK DIAGRAM OF THE ECONOMETRIC MODEL

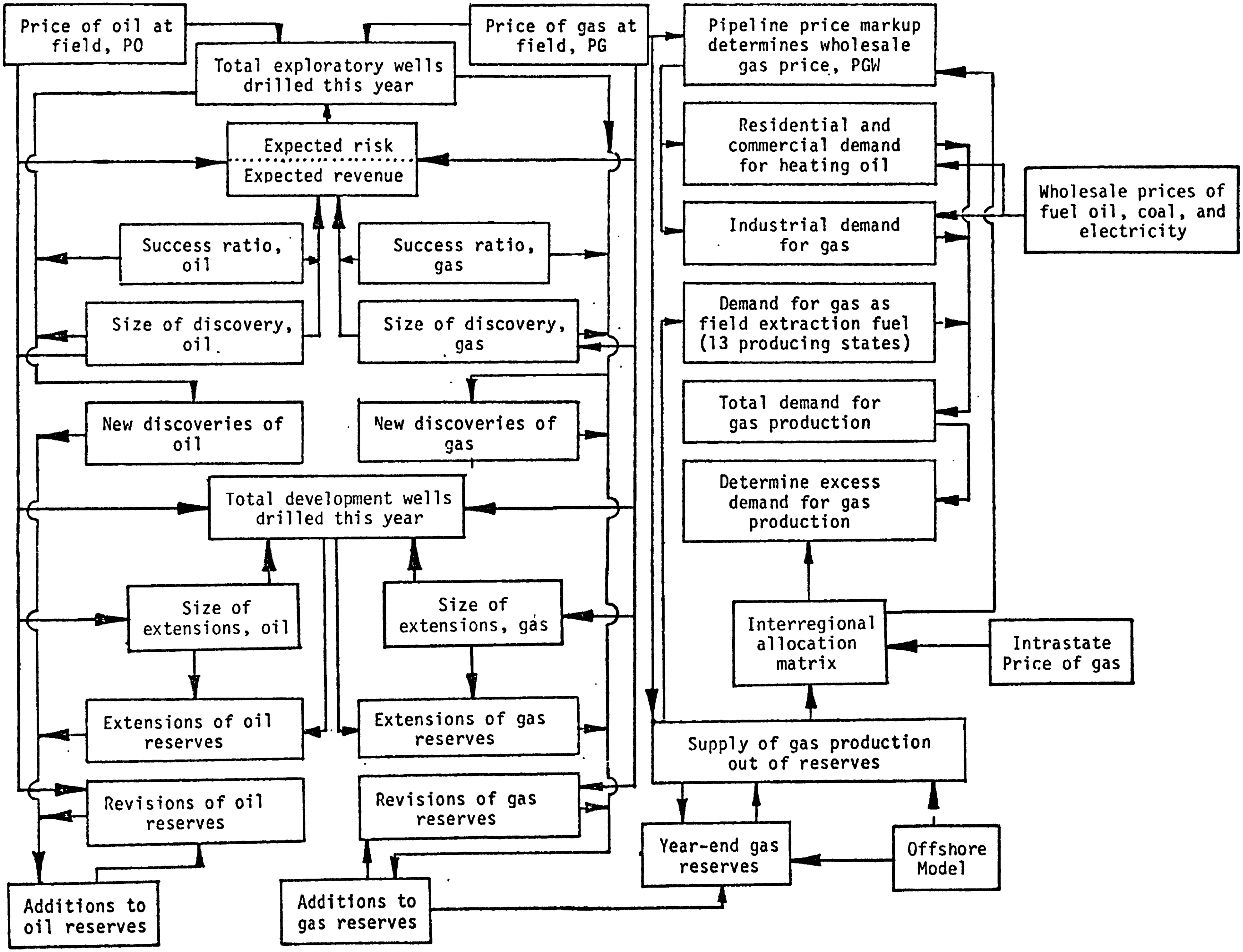

FIGURE 3. SIMPLIFIED BLOCK DIAGRAM OF THE REVISED ECONOMETRIC MODEL

Block	Variables Explained	Number of eq.	Estimation Method
Reserves	Exploratory wells (WXT)	1	GLS with single p for all districts
	Size of discovery, gas and oil (SZG, SZO)	2	
	Extensions, gas and oil (XG, XO)	2	
	Revisions, gas and oil (RG, RO)	2	
Production (onshore)	Production out of reserves (QG), for each of 3 regions	3	GLS with TSLS
Offshore model	Acreage, reserves, production (WWT, DG, XRG, FWT, QG, ACRD, ACPN)	7	Second-order serial correlation with TSLS.
Price markup	Wholesale gas price (PWG)	1	GLS
Wholesale gas demand	Res.-comm. demand (TRCS) and indus. demand (TINS) for each of 5 regions; Extraction fuel demand (FS)	11	GLS with TSLS
Wholesale oil demand	Res.-comm. demand (QO2) and indus. demand (RSID) for each of 3 regions	6	GLS
Interregional	Input-output coefficients	-	
	Intrastate allocations (PCT) for each of 2 regions	2	GLS

TABLE 1. ESTIMATED EQUATIONS OF THE MODEL

Variable	Version 3 Simulation Error[a]	Version 4 Simulation Error[b]	Version 3 Mean Actual[a]	Version 4 Mean Actual[b]
Exploratory wells, onshore	Mean: 347 rms: 718	Mean: -742 rms: 1019	6038	5993
Successful oil wells	Mean: -69 rms: 123	Mean: -72 rms: 163	343	477
Successful oil wells	Mean: -79 rms: 161	Mean: -105 rms: 151	678	606
Discoveries of gas	Mean: 1.4 rms: 2.4	Mean: 0.0 rms: 1.1	4.6	3.9
Discoveries of oil	Mean: -0.01 rms: 0.08	Mean: -0.05 rms: 0.09	0.25	0.25
Extensions of gas	Mean: 2.0 rms: 2.6	Mean: 0.1 rms: 1.0	7.2	6.3
Extensions of oil	Mean: 0.0 rms: 0.05	Mean: -0.03 rms: 0.06	0.52	0.45
Revisions of gas	Mean: 1.4 rms: 2.3	Mean: -0.2 rms: 1.1	-0.1	-1.4
Revisions of oil	Mean: -0.09 rms: 0.38	Mean: -0.22 rms: 0.42	1.39	1.26
Additions to gas reserves	Mean: 4.8 rms: 6.3	Mean: 0.2 rms: 2.1	11.8	8.7
Additions to oil reserves	Mean: -0.10 rms: 0.41	Mean: -0.29 rms: 0.47	2.16	1.96
Production of gas	Mean: 0.1 rms: 0.4	Mean: 0.3 rms: 1.0	21.5	18.9
Northeast gas demand	Mean: -0.14 rms: 0.15	Mean: -0.05 rms: 0.07	3.74	3.82
North Central gas demand	Mean: -0.17 rms: 0.20	Mean: -0.18 rms: 0.19	4.14	4.28
Southeast gas demand	Mean: -0.06 rms: 0.07	Mean: -0.04 rms: 0.07	1.56	1.62
South Central gas demand	Mean: -0.31 rms: 0.42	Mean: -0.25 rms: 0.38	8.15	8.37
West gas demand	Mean: -0.11 rms: 0.11	Mean: 0.02 rms: 0.05	3.55	3.63

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[a] Simulation period is 1967-1972.

[b] Simulation period is 1968-1974.

[c] Includes both onshore and offshore production.

TABLE 2. HISTORICAL SIMULATION COMPARISON OF VERSION 4 AND VERSION 3 OF NATURAL GAS MODEL

3.1 MODEL HISTORY

a.	Name	Coal Policy Model
b.	Developer:	Martin B. Zimmerman, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts
c.	Duration:	1976-continuing
d.	Location:	MIT, Cambridge, Massachusetts
e.	Sponsors:	Energy Research and Development Administration, Office of Planning and Analysis, Task Order Number 16; Council on Wage and Price Stability; Center for Energy Policy Research, MIT

3.2 MODEL DESCRIPTION

a. Summary

The Zimmerman Coal Policy Model consists of four components: the coal supply model, the transport-cost model, the demand model, and the linear programming link between the models. The complete model is a sequential supply and demand model for the years 1975-2000 and contains econometric, linear programming, and behavioral submodels. The models and their integration attempt to capture a highly complex industry and regulatory regime, while keeping the overall structure simple enough so it does not conceal the basic workings of the industry.

Figure 1 (see page 54) provides a schematic overview of the coal policy simulation model. Given an initial set of prices, the model determines the initial demand for coal by demand region. These demands are passed to the linear program as constraints. The supply model establishes the cost of producing coal as a function of output by sulfur content and by region. The transport model determines the cost to transport coal from minemouth to demand center. The linear program then minimizes the cost of mining and transporting the coal needed to meet the regional demand, subject to limitations on sulfur emissions in each region.

The solution of the linear program yields output by region and sulfur content, flows of coal from supply region to demand region, and the delivered price of coal to each region. The delivered prices are passed back to the demand model to estimate a new set of regional demands. The coal outputs are fed back to the supply model to establish a new set of supply prices, and the process is repeated. In theory one could operate back and forth until convergence is achieved to a set of prices consistent with instantaneous equilibrium in supply and demand. In practice, the models are run recursively. The demand in year t is a function of price in year t-1. This reduces considerably the computational complexity of the model without introducing any serious distortion. This is so because demand changes in response to price changes take many years to make a completely adjust. In any year the demand is quite inelastic with respect to prices.

The linear program is solved each year. However, the output in any given year affects coal prices throughout the simulation period. The essence of the supply model is the "cumulative" cost function. This function estimates how cost increases as output cumulates over time. In each year, the cost of producing any given amount of coal is updated to reflect cumulative output through that year.

The following is a brief description of the different components of the coal policy model.

The Coal Supply Model

The coal supply model is a disaggregated model developed specifically with the goal of policy analysis. Depletion and regulatory policies are continually modifying the structure of the industry. The problem is one of predicting industry structure, since the structure is continually changing. The Zimmerman Coal Supply Model attempts to deal with this problem. The basis of the supply model is a cumulative cost function. This function yields long-run marginal cost as a function of cumulative output and thus captures the effect of depletion. Structural change occurring through policy action is handled by the various levels of aggregation. Sulfur regulations, for example, change the demand for coals of various sulfur levels.

There are three main steps to the estimation process. In the first step a cost function is estimated that explicitly accounts for the impact of geology on the cost of production. The second step establishes the distribution of coal in the ground according to the geological characteristics of the deposit. Finally, the cost function is combined with the reserve distribution to yield the cumulative cost function.

These cumulative cost curves have been made sensitive to policy variables. The model has also been programmed to accommodate policy changes by effecting the appropriate shift in the distribution.

Although the supply model can be used separately to evaluate the marginal production costs under various assumptions, the information it provides is too detailed to be handled and integrated with the other components of the model. For integration with the rest of the model, the strip and deep cumulative cost curves have been summed, as well as the state supply functions, to create six supply regions. The sulfur categories have also been aggregated to eight intervals. The result is six regional supply functions for eight sulfur categories for a total of 48 supply curves. The supply model is then used to build aggregate supply curves by calculating the marginal prices for the individual regions within an aggregation. These are used to build piecewise linear supply-cost curves for the LP portion of the model. The state detail is not used in the regional model yet is available, if needed, for policy analysis.

The Transport Cost Model

The supply model determines prices at the minemouth. However, a significant proportion of the delivered cost of coal is transport cost. The predominant mode of transport for large scale coal shipment is the unit train. The rates charged by railroads to haul this coal result from a bargaining process between railroads and coal users. Finally, the rate that emerges is subject to regulation by the Interstate Commerce Commission. From a modeling standpoint, the eventual outcome of the bargaining process is indeterminate. The indeterminacy arises for two reasons. First, key factors affecting the bargaining process are unobservable. Second, even if the conditions were observed, there is an inherent indeterminacy in a bargaining process between lateral monopolists. The transport cost model deals with the stochastic nature of the bargaining process and arrives at a rate equation. The supply model together with the transport rate equation yields a delivered cost of coal.

The Demand Model

The demand for coal is derived from the demand for electricity and from the demand for industrial products. A modified version of the Baughman-Joskow Regional Electricity Model (REM) is used to calculate the utility and industrial coal demand. The model has been modified to take account of the richness of environmental policy explicitly considered in the coal supply model. Demands for metallurgical and export coal are specified exogenously. The REM Model contains a fairly detailed, nine-region behavioral model of the electric utility industry, which incorporates operational level decisions with interfuel competition, as well as strategic level planning of new generating facilities. For example, sulfur emission levels may be set by regions, and scrubbing devices may be retrofitted to existing plants. The non-utility sector uses econometric equations to calculate total energy demands and fuel spilts, based on relative prices and lag effects for the industrial and the residential and commercial demand sectors.

The Link Between the Supply and Demand Models

The first step in the link between supply and demand modes is a linearization of the cost curves. The highly non-linear cumulative cost functions are approximated by step functions. The program chooses the level of output from each step. Clearly, lower-cost steps are used before higher-cost steps.

The linearized supply curves and the demand model are linked through a linear programming formulation. The supply and transport models yield the cost of producing and transporting coal from supply region to demand region. The demand model yields coal demanded by the nine U.S. census regions. This is then disaggregated into 12 smaller demand regions and fed to the linear program as constraints. The linear program minimizes the cost of meeting these demands given mining cost and transport cost and subject to additional constraints on the sulfur content of the coal.

Demand in year t is a function of prices in year t-1. That is, demand adjusts with a one-year lag. Given the nature of the purchasing decision by electric utilities, this is not unrealistic. Furthermore, price changes from year to year are relatively small in this long-run model and demand elasticities in the short run are small, so results are never far from the equilibrium set of prices and outputs.

The linear program is solved year by year. However, mining costs in each year are updated given the additional cumulative output represented by last year's output. Each year a new set of step functions is calculated. In this way depletion is explicitely accounted for.

The interactions through time are captured partially by this depletion phenomenon. Further, the demand model bases its decisions on expected future costs. However, the solution to the dynamic program is not a full dynamic solution.

Policy Simulations

The model has also been used to explore the effects of several proposed national policies that are now causing much controversy. Among the issues being examined are western coal development, taxation policy, nuclear power as an alternative to coal, and control of air pollution emissions. Policy is simulated in this model by changing the values of exogenous inputs. The impact of higher transport costs are assessed by raising rates predicted by the transport model. Sulfur pollution laws are examined by changing constraints in the linear program. Taxes are examined by altering the level of state taxes.

Some of the findings from the different scenarios are displayed in Table 1 (see page 53). In this table, the row entitled "current scenario" displays regional coal production needed to meet at the lowest cost the demands of the electric and industrial sectors in the year 2000. Implicit in the projections are delays in nuclear power development such as those now occurring, gradual solution of the problems, and eventual renewed growth of nuclear power production.

The second row shows future coal production assuming a total moratorium on new nuclear power plants; only those now under construction are developed. The effect of a nuclear moratorium on coal production is drastic. The Midwest and Montana-Wyoming areas are particularly impacted. The Midwest must produce one and a half times what it produces under the current scenario, and Montana-Wyoming over two and a half times of what it produces under the current scenario. To put these quantities into perspective, under a free moratorium, the total production from the Midwest and Montana-Wyoming must equal roughly two and a half times the total production of the United States in 1977.

The environmental implications of such an expansion are staggering and likely to lead to policy reaction. Since the West is most impacted by the production increase, the researchers investigated the effects of adopting a policy of tight leasing in those states. Assuming that no more leases for coal mining are awarded in the West, production must rise in all other areas. This time Colorado-Utah is most affected: Under a full nuclear moratorium and tight leasing, these states must produce two and a half times their production under either the current scenario or the full moratorium alone. The Midwest is also called on to increase its output still further under the full nuclear moratorium and tight-leasing.

The effect of the nuclear and environmental policies on the price of electricity to residential consumers are significant. The model predicts that the cost of electricity in the year 2000 will be 12 percent higher in the event of a nuclear moratorium than under the current scenario. If the nation simultaneously adopts tight leasing in the West, the cost will be 17 percent higher than under the current scenario. Because of the long-run equilibrium nature of this model, it is likely that these cost estimates are likely to be lower than the true costs.

Conclusions

The model has been used to assess the forces shaping the future of the U.S. coal industry and takes a broad look at the evolution of the industry. It has examined how such basic forces as sulfur regulations, labor cost trends, and shifting demand centers are shifting production to the west, whereas the developments pulling eastward are policy related. This tug-of-war between policy and basic forces will determine how much western coal moves east.

These forces are also shaping the structure of the coal industry. The results of the analysis indicate that coal will be used primarily by electric utilities. Industrial use of coal grows but still remains a relatively small fraction of total consumption. The historical decline of coal consumption by the industrial sector will be reversed, but its rate of expansion will not be great enough to overtake utility consumption. The model also estimates a decline in oil and gas consumption. The other areas of coal demand that will account for some of the coal expansion are domestic, metallurgical coal, metallurgical and steam coal exports, and synthetic fuel needs. The first three of these sectors have been treated as exogenous. The latter two demand categories will depend upon coal prices. The study points out that although synthetic fuels derived from coal are not economic at present, given the rapid escalation in real oil prices they will become economic in the future. A similar conclusion applies to steam coal exports. The sum of exports and synthetic fuel demand could total as much as 20% of total coal use by 2000.

The fact that the electric utility section accounts for the bulk of coal consumption explains a good deal about the nature of the trade-offs to be considered when formulating coal policy. The integrated coal and electric utility model allows a consideration of the trade offs between environmental policy and oil imports.

The major effect of environmental controls on oil consumption is in the industrial sector. The imposition of sulfur standards has a fairly large impact, increasing oil consumption in the year 2000 by over one million barrels per day. Thus, clean air requirements will increase oil imports. The other policies considered -- BACT, a leasing moratorium, transport rate increases, and a nuclear moratorium -- have little incremental effect on oil consumption. This puts the current policy debate into perspective. Given sulfur regulations, the focus of the debate turns away from oil imports to the other trade-offs that must be made. The analysis has isolated three key elements in coal policy. These are western coal, eastern high-sulfur coal, and nuclear power. These are the three safety valves in the system and each of them plays an important role. The trade-offs to be made are between western low-sulfur coal, eastern high-sulfur coal, and nuclear power. The issues of realistic concern are nuclear safety and waste disposal problems versus increased strip mining and the increased use of high-sulfur coal, and potential problems from atmospheric build up of CO_2. Since the lags in the system are long, most of these problems will become manifest in the 1990s.

The model is neither expected to make policy recommendations nor to make forecasts. Instead it quantifies the impact of various policies in a consistent framework, thereby providing information that policy makers--and private citizens--can use in weighing the costs and benefits of possible policy alternatives. The model is a tool for analysis of the relative impacts of alternative policies.

b. Database

The data inputs for two of the four components of the coal study--the supply model and the transport cost model--are described briefly below. The demand data is described in the REM section of this directory. The CP link has no supporting data. Documentaion of the data used has not yet been completed by the researchers.

Supply Model Data

Coal cumulative cost functions are disaggregated by state, sulfur category, and mine type. These are then aggregated to six regional supply functions for each sulfur category. Thus, 48 cumulative cost curves are fed as inputs to the linear program. The state-level detail can be recovered after each simulation by using the aggregation process in reverse. All disaggregated information is obtainable after each simulation.

Regions	States	Bureau of Mines Districts
Appalachia	Pennsylvania Northern West Virginia Ohio, Maryland	1, 2, 3, 4, 6
Southern Appalachia	Southern West Virgina Virginia, Eastern Kentucky Tennessee, Alabama	7, 8, 13
Midwest	Illinois, Indiana West Kentucky	9, 10, 11
Powder River Basin	Montana, Wyoming	19, 22
Utah, Colorado	Utah, Colorado	16, 17
Arizona, New Mexico	Arizona, New Mexico	18, part of 17

Sulfur Categories

1) 0-.64
2) .65-1.04
3) 1.05-1.44
4) 1.45-1.84
5) 1.85-2.24
6) 2.25-2.64
7) 2.65-3.04
8) 3.05+

Cost Function

The data used to estimate the cost function for deep mining were seam thickness, the number of sections in the mine, and the number of openings to the seam. Estimation of the cost function for strip mining required data on dragline size (as a measure of productivity), overburden to be removed per foot of coal, and the number of draglines used.

Expenditures

Deep-mining capital expenditures for three classes of capital equipment, labor, and supplies were estimated. The data used for capital expenditures, overhead, and supplies were engineering estimates for hypothetical mines from the Bureau of Mines. Labor data came from 1978 unions' pay scales and UMW charges were added. Strip-mining expenditures were estimated using engineering estimates from the Bureau of Mines, and data on sizes and costs of draglines obtained from dragline manufacturers.

Reserves

Reserves data in seam widths between 28 inches and 42 inches and greater than 42 inches were obtained from the U.S. Bureau of Mines. Data for representative Eastern and Western coal regions were used to approximate the statistical distribution.

Transportation Model Data

Historical

Unit-train rates were obtained from surveys for the Eastern, Midwestern, and Western regions. The rates are converted to current dollars using the American Association of Railroad indexes and appropriate escalation formulae.

c. Computer Aspects

All of the elements described above in the Zimmerman Coal Policy Model are implemented as computer programs, which are then solved sequentially by year. The procedure is basically as follows:

1. The supply model calculates new cost curves, based on the current reserve commitments and other specified assumptions such as tax rates, inflation, etc. The program is written in FORTRAN IV.
2. The demand model calculates current year demand based on previous year prices and other factors and is writen in FORTRAN IV.
3. A program written in PL-1 uses the supply and demand sources of information and links it to the transportation/allocation LP model, which uses the MPSX programming system and determines the actual quantities delivered from each supply region and the marginal prices at the demand regions.
4. These quantities and prices are then passed back to the supply and demand model and steps 1-3 are repeated for the next year.

All the above programs operate on IBM-VM/370 and are stored on magnetic tapes.

3.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The integrated model of coal supply and demand has been used to assess a wide range of trade-offs and costs involved in various United States coal policy options. Policy simulations have been performed for the following issues: Western Coal Development Taxation policy, nuclear as an alternative to coal, and control of air pollution emissions.

The Integrated Coal Analysis Model developed by David E. White at the Massachusetts Institute of Technology Energy Laboratory uses the Zimmerman Coal Supply Model, for a dynamic solution of the coal supply model and transport models.

The model is also being utilized by a number of organizations around the country. For instance, Data Resources Incorporated, uses a slightly different version of the Coal Policy Model to study coal markets and the impact of state and federal government regulations on the coal industry. Gulf Oil Corporation has made use of the Coal Supply Submodel. Currently the author plans to study the effects of contract structure between the users and the mine owners on the evolution of the coal industry. Attempts are also being made to improve upon modeling the electric utility demand for coal.

3.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS

Zimmerman, M.B., An Economic Interpretation of Coal Reserve Estimates, MIT Energy Laboratory Working Paper No. MIT-EL 79-048WP, July 1979.

In this paper, the author discusses how coal reserve data have been and can be used to analyze the impact of cumulative output on the future cost of coal.

Zimmerman, M.B., "Modeling Depletion in a Mineral Industry: The Case of Coal," The Bell Journal of Economics, Vol. 8, No. 1, Spring 1977.

This paper has a two-fold purpose. The wider and more abstract purpose is estimating the long-run marginal cost of producing a depletable resource. The second purpose is the illumination of several important policy issues dealing with the development of coal resources. The essence of depletion is the movement from cheaper to more costly deposits. Econometric models estimated from past observations on prices and outputs cannot capture this movement, since the past reflects only the more favorable deposits.

This paper develops an analysis for coal based on the geology of remaining deposits. A "cumulative" cost function is estimated. This function describes how the incremental cost of coal behaves as output cumulates over time. In the first part of the paper a long-run cost function is estimated. Costs are related to output and to the geological characteristics of the coal seam. The second part of the paper combines this cost function with data on the geology of deposits to yield the cumulative cost function. The last section of the paper discusses the implications of the estimation for policy choices relating to strip-mining regulation, air pollution legislation, and energy independence.

Zimmerman, M.B., "Rent and Regulation in Unit-Train Rate Determination," The Bell Journal of Economics, Vol. 10, No. 1, Spring 1979.

Railroads and utilities bargain over rates for hauling coal. In the past, the price of alternative fuels has served to limit those rates. Recently, these limits have been raised by regulation-induced shortages in natural gas, cartel-induced price rises for oil, and environmental opposition to nuclear power. This article estimates a model of the rate-making process and examines how the process has responded to increased prices of alternative fuels. The results indicate that railroads have been moderately successful in taking advantage of these higher prices. However, their success is increasingly leading to challenges before the Interstate Commerce Commission.

Zimmerman, M.B., Estimating a Policy Model of U.S. Coal Supply in Advances in the Economics of Energy and Natural Resources." Pindyck, R.S. (ed.), JAI Press, Greenwich, Connecticut. Vol. 2, 1979.

This paper developed a method for dealing with structural change in a mineral industry. Depletion and environmental regulations are continually changing the supply responsiveness of the coal industry in the United States. Traditional econometric analysis is inadequate in the presence of this structural change. To deal with depletion, this paper based its estimates of long-run supply upon the geology of remaining deposits. To deal with environmental regulations, cumulative cost curves were estimated separately by type of mining and by type of coal. The evolution of coal costs will depend crucially upon policy choices. There are, however, other factors this paper has not discussed that will greatly affect the cost of coal. Finally, technological change over the truly long run will have the greatest impact on the evolution of coal prices.

Zimmerman, M.B., The U.S. Coal Industry: The Economics of Policy Choice, MIT Energy Laboratory Working Paper No. MIT-EL 80-012WP, December 1979, revised March 1980.

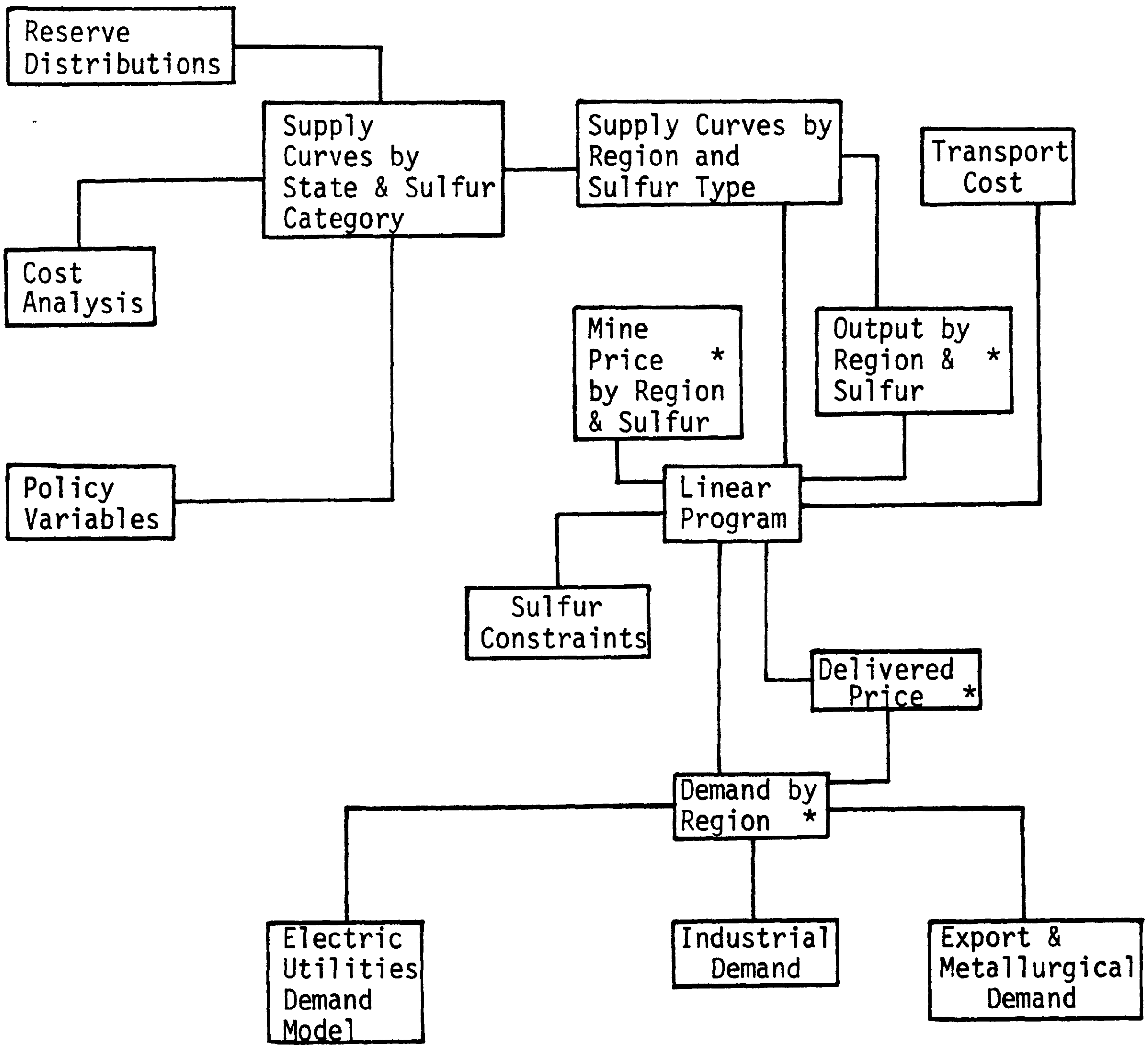
The coal industry is being called upon to play a larger role in supplying U.S. energy needs at a time of increasing environmental concern and regulation. It is clear that trade-offs will have to be made. These may be made explicitely or, more likely, fragmented decision making will lead to policies that never explicitly consider the trade-offs and interactions. This is the subject of the monograph.

The second chapter of the monograph presents the model used for policy analyses. The model consists of two submodels linked together by a linear program. Chapter 3 uses the model to analyze the basic forces shaping the coal industry and focuses on the effects of factor price changes. Chapter 4 superimposes environmental policy on factor price changes and assesses the effects of those policies. Chapter 5 looks at the interaction of nuclear policy with the environmental controls on coal. The concluding chapter brings the various analyses together for discussion of the broad policy decisions facing the United States.

REGIONAL COAL PRODUCTION IN THE YEAR 2000
(millions of tons per year)

Assumptions	Total	East	Midwest	Montana-Wyoming	Colorado-Utah	Arizona-New Mexico
Current Scenario	1619	419	284	749	78	90
Full Nuclear Moratorium	2408	490	725	1029	80	84
Full Nuclear Moratorium and Tight Leasing	2237	540	983	493	204	16

TABLE 1. REGIONAL COAL PRODUCTION UNDER ALTERNATIVE SCENARIOS



* model outputs

FIGURE 1. COAL POLICY MODEL: MODEL STRUCTURE

II. CURRENT-ACTIVE MODELS AND ASSOCIATED DATA COLLECTIONS

1.1 MODEL HISTORY:

a. Name:	Industrial Energy Demand Model (KLEM)
b. Developers:	David O. Wood, Energy Laboratory and Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts Ernst R. Berndt University of British Columbia, Canada
c. Duration:	April 1975 - continuing
d. Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e. Sponsors:	Energy Laboratory; National Science Foundation

I.2 MODEL DESCRIPTION

a. Summary

The industrial energy demand model (KLEM) is an empirical study based on the concept of derived demand for energy and explicitly investigates cross-substitution possibilities between energy and nonenergy inputs. An attempt has been made in this study to characterize completely the structure of the United States manufacturing 1947-1971, by providing evidence on the possibilities of substitution between energy and nonenergy inputs. The results of this research have important applications in the formulation and analysis of resource conservation and economic growth policy.

The model assumes the existence of an aggregate production function for United States manufacturing that relates the flow of gross manufacturing output to the four inputs: capital (K), labor (L), energy (E), and other intermediate materials and services (M). Corresponding to this aggregate production function is a cost function, that reflects the underlying technology. The model specification employs the translog functional form as a second-order approximation to the underlying cost function, assuming constant returns to scale, Hicks-neutral technical progress, and competitive factor markets. The translog is one of several flexible functional forms that impose no *a priori* restrictions on the Allen partial elasticities of substitution among inputs. An iterative three-stage least-squares method has been used to obtain the solution of the factor demand model in United States manufacturing.

The principal finding from the above econometric study is that technological possibilities for substitution between energy and nonenergy inputs are present but to a somewhat limited extent. Specifically, the findings are: i) energy demand is price responsive--the own price elasticity is about -0.5; (ii) energy and labor are slightly substitutable--the Allen partial elasticity of substitution between energy and labor ($_{EL}$) is about 0.65; and (iii) energy and capital are complementary-- $_{EK}$ is about -3.2. The validity of the value-added specification used in studies and production behavior were also considered and it was found that the data did not support the specification. Some of the policy implications of this study are that the lifting of price ceilings on energy types would tend to reduce the energy and capital intensiveness of producing a given level of output and increase the labor intensiveness. Moreover, since investment tax credits and accelerated depreciation allowances reduce the price of capital services $_{KE}$ 0, implies that these investment incentives generate an increased demand for capital and for energy. To the extent that energy conservation becomes a conscious policy goal, general investment incentives may become less attractive as fiscal stimulants.

b. Data Base

The data on which the KLEM model are based were derived from the interindustry flow tables developed by Jack Faucett's Associates. The tables include both materials and energy input. The KLEM modelers used an older version of the interindustry flow tables to compute price and quantity indices of energy and all other intermediate materials.

An updated and expanded version of the data base has been obtained and will be used in the re-estimation of the "Dynamic Model of Industrial Factor Demands" and "Industrial Factor Demands with Disaggregated Inputs." The variables computed from the original data are briefly described below. The updated version will also be described.

Price and Quantity Indices for the KLEM Model

Data from the Input-Output Tables on annual interindustry flows of goods and services from 25 producing sectors to 15 consuming sectors were used to construct the energy quantity indices for the KLEM model. The data series used were the purchases of coal, crude petroleum, petroleum products, natural gas, and electricity by establishments in United States manufacturing. The total values of the purchases in current and constant dollars were also obtained from the tables. A price index for energy was then constructed using the value and quantity data.

Intermediate Materials

Quantity indices for all other intermediate materials were constructed for all years using the Input-Output Tables. The value of intermediate goods was computed as the sum of all dollar purchases for nonenergy goods from data available in current and constant dollars. A price index was derived using the values and quantities series. The Input-Output Tables were compiled from data obtained from the following sources: the Bureau of Mines' Mineral Yearbook, Census of Minerals Industries, Census of Manufacturers, United States Department of Commerce Input-Output Tables, Annual Survey of Manufacturers, and various secondary sources.

Updated Interindustry Flow Tables

The current version of the Input-Output Tables consists of four series for the years 1958-1979 for 35 input-output sectors. These are: end uses of strategic materials in current and constant dollars, and both total and first transactions of strategic materials and energy products, in current and constant dollars.

c. Computer Aspects

The KLEM model and its associated data base are stored on magnetic tape through the TSP computer system, operating on the IBM VM/370.

The updated data are stored on magnetic tape in a format compatible with FORTRAN programs. The technical information required to read the tape is available, as are printouts of the tables. Documentation of the updated data, such as a description of sources and methodology, is not available.

1.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The model of factor demand in United States manufacturing has been used as a framework for evaluating the long-run consequences of changes in relative input factor prices. For instance the model has been employed to calculate the historical effects of two nonenergy policies: 1) the effects of adjusting the price of capital services to stimulate the influence of the investment incentives in the sample period, and (ii) the effects of the Social Security payroll tax under alternative assumptions about the tax incidence. The purpose is to illustrate the influence of these economic growth and social welfare policies on factor demands, particularly energy.

New theoretical and empirical research currently is being conducted in this field by David O. Wood at the Massachusetts Institute of Technology, Cambridge, Massachusetts, and Ernst R. Berndt at The University of British Columbia, Canada, in the following areas:

1) the factor demand studies are being extended by formulating and implementing a dynamic specification to explicitly distinguish short- and long-run input factor interactions, namely, "The Dynamic Model of Industrial Factor Demands";

2) new research is taking place in terms of extending, to the extent possible, the factors explicitly included in characterizing the underlying production technology, namely, "The Industrial Factor Demands with Disaggregated Inputs"; and

3) the models are also being implemented by employing a set of "new updated" data.

1.4 LIST OF WORKING PAPERS AND ARTICLES (generated by the KLEM Project)

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

> This technical paper develops the analytical framework of the KLEM model and gives a detailed account of it.

Berndt, E.R. and Wood, D.O., "Engineering and Econometric Interpretations of Energy-Capital Complementarity," The American Economic Review, Vol. 69, No. 3, June 1979.

> The purpose of this paper is to provide a reconciliation of the apparently conflicting evidence of energy-capital substitutability provided by other econometric studies. An analytical framework has been developed that reconciles the engineering evidence with the possibility of E-K complementarity. Empirical evidence has also been provided that reconciles the disparate econometric results of E-K complementarity and substitutability.

Wood, D.O., "Economic Policy and the Demand for Energy in United States Manufacturing," American Statistical Association, 1978 Proceedings of the Business and Economic Statistics Section, August 1978.

> The purpose of this paper is to illustrate the potential impacts upon energy consumption in United States manufacturing of economic and social welfare policies, such as the investment incentives and the Social Security payroll tax. These policies have been interpreted in terms of changes in relative factor prices, which are then combined with a simple model of United States manufacturing input demand to estimate the impact of the policies upon factor demands. While the estimated model does not include the manufacturing output price elasticity, the simulation model is augmented to include such a relationship parametrically. Applying the model to an analysis of the possible effects of the investment incentives and the Social Security payroll tax upon factor demands indicate that historical energy demand was significantly affected by these policies.

2.1 MODEL HISTORY

a. Name:	MIT Energy Laboratory Energy Macro-Model (MELEM)
b. Developers:	Robert E. Hall, Stanford University, Palo Alto, California Knut Anton Mork, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c. Duration:	May 1978-continuing
d. Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e. Sponsors:	MIT Center for Energy Policy Research; National Science Foundation

2.2 MODEL DESCRIPTION

a. Summary

The Energy Macro-Model is a small but complete macroeconomic model with an explicit treatment of energy. It is used to analyze the effects of energy price shocks on inflation, employment, and economic activity. It takes into account short-run effects, such as inflation, financial tightening, and temporary drop in investment, as well as long-run changes in the economy's growth path. The supply and demand sides of the economy are both explicitly modeled. Goods are produced by three factors: capital, labor, and energy. The price of energy is determined outside the model; the wage rate is rigid in the short run; and capital formation is subject to a lag. The demand for goods is composed of consumption, which is determined by permanent income, investment, government expenditure, and net exports. The price of goods is determined by unit cost. The financial sector is compressed into a money demand function. The model assumes rational expectations, but includes some important rigidities as well.

The model has been used to analyze the energy price shocks of 1973-74 and 1979. For both cases, the results indicate serious dislocations of the economy as a result of energy price shocks. The model explains most of the 1974-75 recesssion and all of the extraordinary inflation in 1974 as a result of the 1973-74 energy shock. A similar, although weaker dislocation is predicted for 1979-80.

b. Data Base

The data base associated with the model is the data for aggregate factor demand, documented separately in the Database Inventory entitled Energy Macro Data Base.

Computer Aspects of the Model

The model is programmed in FORTRAN and implemented on the CMS system. Three versions of the model exist, with starting dates of 1974, 1979, and 1980, respectively. A new version with a more efficient solution algorithm is in progress.

2.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENTS

Applications so far include simulations of the energy shocks of 1973-74 and 1979, as well as analysis of possible offsetting macroeconomic policies.

Planned future development is in the various parts of the model: factor demand, financial sector, export demand, consumer durables, and inventories. The solution algorithm will also to be improved.

2.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the MELEM Project)

Mork, K.A. and Hall, R.E., "Energy Prices, Inflation, and Recession, 1974-75," The Energy Journal, 1980, forthcoming.

The effects of the 1973-74 energy price increase are traced through the economy. The shock worked via two principal channels. On the one hand, the induced factor substitution permanently lowered the economy's growth path. On the other hand, the maladjustment of the economy resulted in a drop in investment. Consumption declined because the higher energy bill is seen to have depressed real income, as did the recession itself. The energy price shock depressed real output by two and a half percent in 1974 and by five percent in 1975. Prices rose by four percent in 1974 and by another two percent in 1975. Monetary and fiscal policies that might have offset the energy shock are considered. The analysis favors monetary adaptation because of its favorable effect on investment. The paper contains an appendix giving a detailed account of the model.

Mork, K.A., "The Dynamic Effects of Energy Price Shocks: A Theoretical Analysis," draft paper, 1980.

This technical paper discusses the properties of the model from an analytical perspective. The dynamic properties are discussed in detail under flexible and rigid prices and with and without money. Proofs are given for some results that are important for the numerical solution of the model.

3.1 MODEL HISTORY

a. Name: Integrated Coal Analysis Model (ICAM)

b. Developers: David E. White, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

Jeremy F. Shapiro, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: 1978-1980

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsors: MIT Center for Energy Policy Research; Operations Research Center

3.2 MODEL DESCRIPTION

a. Summary

The primary objective of the model is to investigate the applicability of mathematical programming decomposition techniques for the integration of large-scale energy policy models. A secondary objective is to explore the application of these techniques to the analysis of a realistic energy problem.

The problem chosen to be modeled is the production, allocation, and consumption of coal in the contiguous United States for a ten-year time period. The model is dynamic in the sense that future events (prices) influence earlier decisions. Besides having multiple time periods, the model is also multi-regional with a number of different supply and demand regions.

The problem is formulated as a mathematical optimization, which permits a precise statement of the various decomposition procedures, and is also related to the economic equilibrium. This requires the integration of three major independent submodels: production, distribution, and demand.

The objective function is stated as minimizing the total discounted production, transport, and utilization costs for the specified time period. Conversely, this could be stated as maximizing the consumer benefit: the difference between the value associated with a given demand level and the associated supply and utilization costs as reserves are depleted. The transport costs are linear functions depending on the amount of coal shipped between supply and demand regions. The utilization costs incorporate both operating and capital expenses within the framework of a linear programming model.

The Integrated Coal Analysis Model (ICAM) is composed of three major sub-elements:

1. Coal supply: A non-linear resource model with six supply regions and two coal types. The formulation is based on work by Martin Zimmerman, and can incorporate a variety of elements such as tax and wage rates, long-term contract effects, etc. as desired.

2. Coal transport: A linear transportation model for the allocation of coal from the supply regions to the specified demand regions. This is a simple model that may be expanded with such factors as capacity limitations, if required.

3. Coal demand/electric utility model: This is a nine region demand model, that contains an utility sector model used to predict the electric utility demand for coal, incorporating both investments and operating decisions. The metallurgical and industrial demands for coal, being relatively inelastic over the time period studied, are specified exogenously.

The integrated model is represented as a dynamic normative optimization model, which obtains a marginal price equilibrium between the submodels. The model is integrated using both resource-directed (Benders) and price directed (Dantzig-Wolfe) decomposition techniques. One major advantage of these techniques was that upper and lower limits to the optimal solution were available. The overall structure of the model is shown in Figure 1 (see page 68).

All of the solution procedures start with the generation of a coarse grid of subproblem solutions for the master problem by spanning the maximum expected range of the subproblem solutions. The decomposition procedures themselves would, if required, generate solutions from a zero level and move toward convergence, but providing this initial rough structure appeared to be more computationallly efficient.

The first approach tried was a pure resource-directed decomposition. The master problem selected both supply and demand quantity vectors, which were passed to the subproblems, which returned equivalent price vectors. That is, the production submodel would return marginal production prices, and the demand models would return the marginal values of increased coal supply. This procedure showed convergence, although it was fairly slow.

The next approach was a combined resource- and price-directed one. Resource-direction was used for the production side, but price-direction was now used for the demand side. In this case, the demand models were presented with the current prices of coal and responded with coal demand quantities and total costs. The advantages of this were: (1) the master problem--estimated delivered coal prices were quite stable, and (2) the demand model responded more smoothly to prices than quantities. From the economic point of view this is also a more natural decomposition: Prices move forward from producers to consumers, who then determine their consumption based on current prices and alternative choices. This procedure worked very well. The demand side cost converged completely within a few iterations, and the supply side (which was non-linear) converged to within a fraction of a percent.

Both resource-directed and price-directed decomposition techniques were used for integrating the submodels. Some of the procedures that were tried proved quite successful in rapidly obtaining a converged solution. The effectiveness of a decomposition method seems to depend both on mathematical criteria and the nature of the subproblem to which it is applied. For example, a price-directed approach worked better than a resource-directed one for a subproblem with low price elasticity, but the proper selection of technique requires some insight into the structure of the problem.

Once the most effective decomposition approach was determined, the model was used to evaluate several important policy issues relating to coal. Some of the questions were: the coal production and demand levels over the span of the model, the change in Eastern and Western Coal production, the demands and prices for different types of coal. Also of interest were some of the dynamic effects associated with users costs and investment decisions. In the current model, the major elasticity of coal demand occurs in the electric utility sector, and two scenarios were run with different estimates of nuclear electric generating capacity.

In the base case, with an estimated nuclear capacity of 174 GW in 1985, the model predicts only a modest increase of 15% in coal production over the ten-year period 1976-1985. The production of low-sulfur coal increased by 77% while the production of high-sulfur coal declined by nearly 30%. [See Figure 2, page 69]. The next case, with an updated estimate of nuclear capacity of 116 GW in 1985, gave a 34% increase in total coal production over the ten-year span of the model. The production of low-sulfur coal was slightly higher, up 86%, while the production of high-sulfur coal declined by only 4.6%. This change represented the replacement of nuclear power plants by coal plants using high-sulfur coal with emission control devices. Low-sulfur coal use, because of its higher price, goes up only slightly.

An important result of the decomposition optimization of the dynamic model was estimates of the rents associated with coal production. These rents are the result of the increasing production costs as coal reserves are depleted. Current production means higher future costs and, depending on the discount rate of the producer, gives a marginal value of current production greater than the current marginal costs. This difference between marginal cost and marginal value can be indentified as economic rent. The model predicted a very high rent for Eastern low-sulfur coal, as high as $6/ton (20% of the marginal cost) in 1976. This is because the resource base for that coal is relatively small, and prices rise rapidly as it is used to meet metallurgical demands. Rents for high-sulfur Eastern coals ranged from $0.83 to $2.25/ton, and rents for Western coals from Montana and Wyoming came to only about $0.20/ton for both low- and high-sulfur coals. The difference in the rents between the two cases studied was quite small because the production changes occurred in those categories with initially low rents. Although a full sensitivity analysis has not been carried out, the dynamic form of this model nevertheless showed significant rents associated with coal depletion effects.

Thus, the study demonstrated the many advantages of using mathematical programming decomposition to integrate energy policy models. These include: (1) the integration of generally incompatible modeling techniques, (2) the use of procedures that guarantee convergence and provide upper and lower limits to the optimal solution, (3) the capability of validating the submodels independently, and the (4) potential for gaining greater insights into the behavior of the submodels and their integration.

b. Database

The data that support the transport sub-model are a transport cost matrix for nine demand regions and metallurgical demand, and six supply regions. The units are 1977 dollars per million Btu, using the Btu conversion factor for the coal type produced in each supply region.

The demand model has nine independent demand regions, and the following variables, used for the base case: capital costs, operating costs, electricity demand, plant availability, installed capacity, and the load demand curve. The data was obtained from standard sources and from other Energy Laboratory research projects.

The data used for the supply model were taken from the Zimmerman Coal Supply Model, with several of the categories aggregated.

c. Computer Aspects

The Integrated Coal Analysis Model (ICAM) consists of three separate components:

1. A nonlinear coal production costing model for coal supply.
2. A combined master problem and coal transportation model.
3. A linear programming demand and electric utility model consisting of nine independent regional submodels.

The supply and demand models are linked to the master problem by the transfer of coal price and quantity vectors. The master problem incorporates this new information and continues until an optimal solution is found or the convergence criteria are met. The program and data flow structure are shown in Figure 1.

Each iteration of ICAM requires the solution of ten LP models, a nonlinear supply model, and the creation of new constraints for the master problem. To do this efficiently required an operating system that would permit executive control of the model components and automated data handling procedures. The model was implemented on IBM's Mathematical Programming System Extended/370 (MPSX/370) with the extended control language option (ECL). This system permits writing control programs in the PL/I programming language, which can call and execute linear programming procedures as well as other computer programs written in PL/I or FORTRAN. Data can be passed back and forth in expansible data structures, LP problems can be modified with the addition of rows and columns, and previous solutions can be saved for restarting.

Thus it was possible to create ICAM in a modular structured form. The executive program executes the separate submodels, controls the data flows, and determines the termination conditions. The supply model was written as a PL/I subprogram that responds with cost derivatives and total cost when sent a supply vector. The master/transportation model is an LP that is solved by a separated PL/I subroutine that calls the LP solution procedures of MPSX/370. Selected data from the master problem are also returned to the executive so it can be sent on to the supply and demand subproblems. Another subroutine takes selected data returned from those subproblems to revise the master problem with new rows or columns. The nine LP demand models are solved by another subroutine that automatically saves the current solutions for the next optimization. The executive program also calculates upper and lower bounds, and can terminate the algorithm when the convergence criteria are met.

The model was run on an IBM 370/168 at MIT's Information Processing Service, using the CMS time-sharing system. Typically the cost of solving a new case from scratch during off-peak hours was about $100. This included creating new problem files for revised master and demand subproblems, creating the initial grid points, and finding a converged solution. About half the cost was in setting up the new problem and half in solving it.

The LP problem statistics before the addition of Benders or Dantzig Wolfe constraints are:

Master/Transport Problem	-	321 Rows,	1544 Variables
Demand Region Submodel (9)	-	161 Rows,	467 Variables

Currently both the program and the data files are stored on magnetic tapes. Details of the implementation procedure and copies of the computer codes can be obtained by contacting the authors.

3.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

There are a number of directions for future research. One direction is toward greater theoretical understanding of the decomposition techniques. For example, can upper and lower limits be determined for problems that use a mixture of decomposition approaches? What limitations does the nature of the subproblems place on the choice and application of decomposition techniques and how can they be overcome? Are there approaches that have theoretically better convergence behavior?

Another direction is toward a wide variety of practical extensions of the integration techniques. The current model could be extended in a number of ways. A number of questions will surely arise during the implementation of any model integration, and with the gaining of practical experience, more efficient approaches will be discovered. Finally, the success of the model integration approach could be extended to the integration of other energy policy models, and to models in other areas.

3.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the ICAM Project)

White, D.E., "The Application of Mathematical Programming and Decomposition Techniques to the Integration of a Large-Scale Energy Model," PhD dissertation, Massachusetts Institute of Technology, January 1980, also, Operations Research Center, Technical Report No. 176, Massachusetts Institute of Technology, March 1980.

This thesis explores the applicability of mathematical programming techniques for the integration of large-scale energy models, and describes their application to the integration of large-scale, dynamic, partially nonlinear, coal supply and demand models. First, the components of a generic coal model are described and several currently available coal models are reviewed. Then a variety of applicable mathematical programming solution techniques, including both price and resource directed decompositions, are discussed. The thesis also describes the creation of an integrated coal analysis model (ICAM) and the results of testing and evaluating a variety of decomposition/integration techniques. The final section includes an analysis of some of the model's policy implications, a critique of the model itself, and some suggestions for future studies and model extensions.

Shapiro, J.F. and White, D.E., "Decomposition and Integration of Coal Supply and Demand Models," Technical Report No. 171, Operations Research Center, Massachusetts Institute of Technology, March 1980.

A number of large-scale models have been proposed and implemented in recent years to study the anticipated expansion of coal production and utilization in the U.S. This paper reports on the application of mathematical programming decomposition methods to the construction and optimization of these models. Results addressing specific coal policy questions are also reported using the decomposition approach.

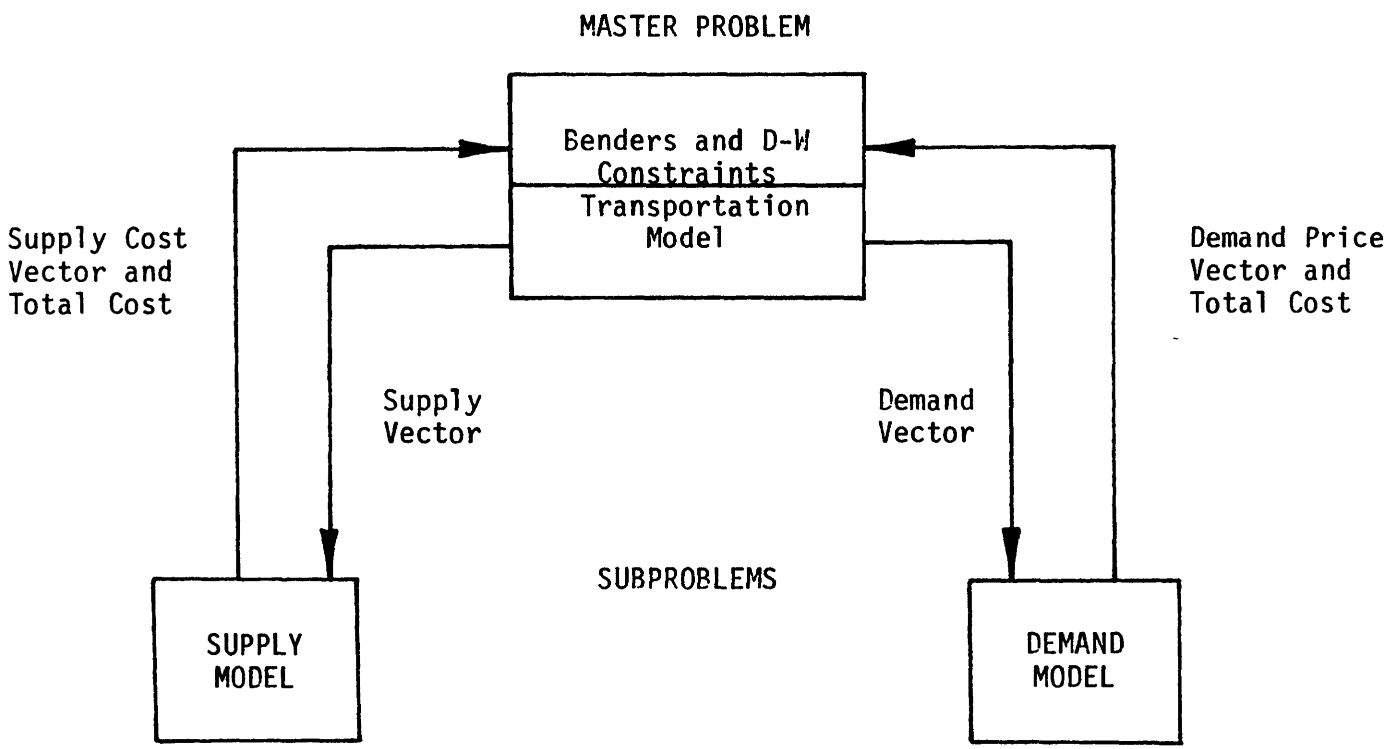


FIGURE 1. PROGRAM AND DATA FLOW STRUCTURE

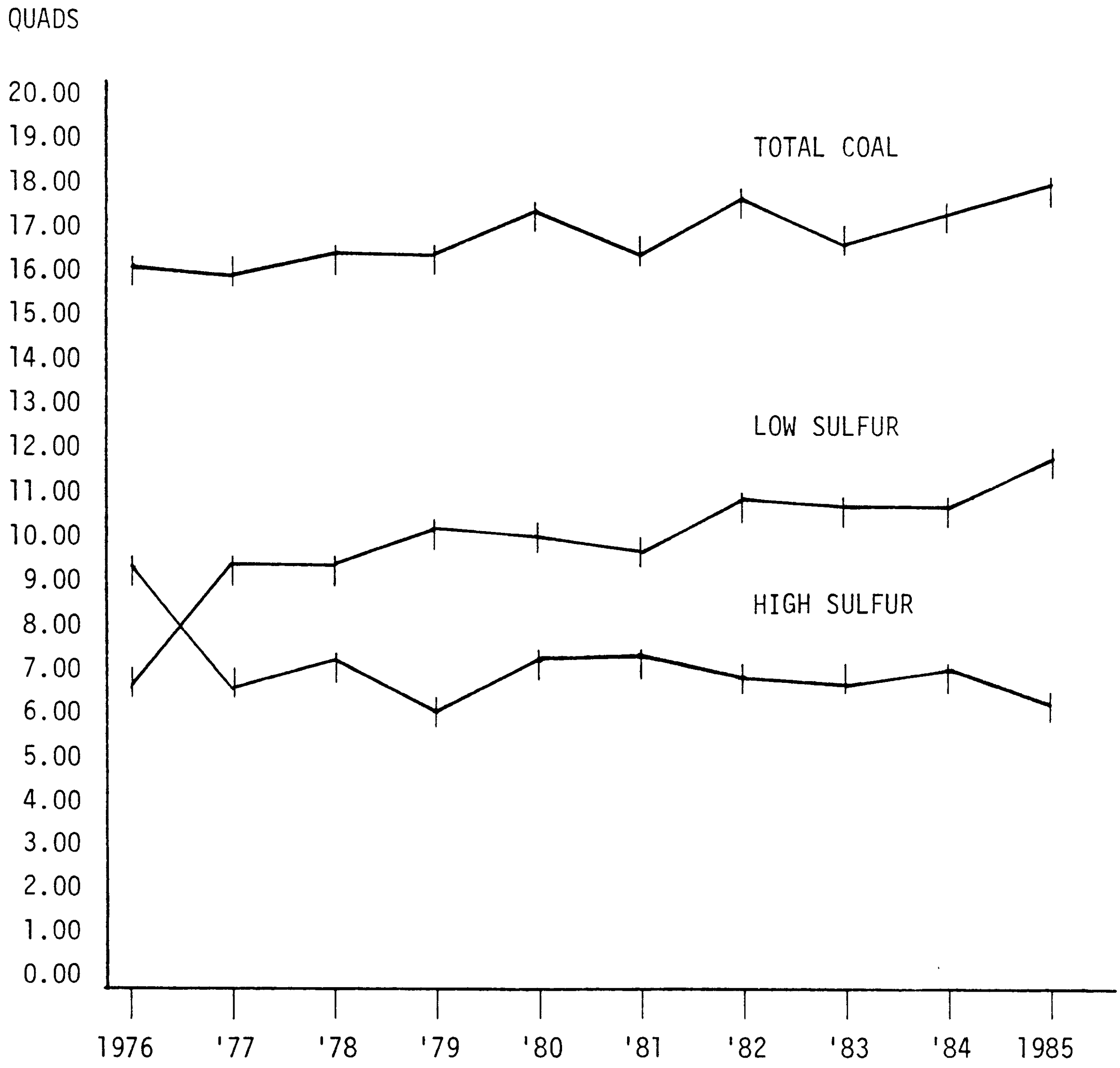


FIGURE 2. BASE CASE COAL PRODUCTION

4.1 MODEL HISTORY

a. Name: Electric Utility System Generation (SYSGEN)

b. Developers: Susan Finger, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

Paul Deaton, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: 1973-1979

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsor: Department of Energy

4.2 MODEL DESCRIPTION

a. Summary

The objective of SYSGEN is to find the least-cost operating schedule of a given set of electrical generators subject to operating constraints and to find the frequency, duration, and probability of loss of load for the generators, given customer demand.

The program uses a modified Booth-Baleriaux technique. This methodology treats plant outages as randomly occurring loads on other plants in a utility system.

The program can handle up to 34 time periods with up to 52 subperiods each and 300 generating units with five valve points. There can be up to 50 conventional hydro units and up to 50 storage units.

In conjunction with SYSGEN, two programs--ELECTRA, a precursor, and and SCYLLA, a post-processor--can be used to evaluate time-dependent electrical generators, such as wind or solar units.

b. Data Base

The program requires the following general information: discount rate, customer load shapes, O&M and fuel escalation rates, immature forced outage correction factors; and for each generating unit: capacity, plant lifetime, fuel cost, variable and fixed O&M costs, heat rate, mature forced outage rate, and a maintenance schedule. Optional inputs are load frequency curves, spinning reserve requirements, loading order; and for generating units: mean time to repair, spinning reserve cost, and penalty factor.

The model does not have a data base per se; however, the EPRI synthetic utilities have been set up in SYSGEN format. Historical load data from Boston, Omaha, Phoenix, and Miami are also available in standard EEI format.

c. Computer Aspects

SYSGEN was written on an IBM 370 in FORTRAN IV.

Development of SYSGEN started in 1973. SYSGEN 2 was completed in 1976 and is designed to run with GEM, the MIT long-range planning model. SYSGEN 3 was completed in 1978 and was designed as a stand-alone version of SYSGEN 2 with improved hydro and plant outage algorithms. SYSGEN 4 was completed in 1979. It includes frequency and duration algorithms, spinning reserve, startup-shutdown costs, storage units, and, with ELECTRA and SCYLLA, time-dependent power plants.

4.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

SYSGEN is currently being used by the MIT photovoltaics project to evaluate the worth of central station and dispersed photovoltaic appliations. Among the outside users of SYSGEN are Science Applications, Inc., Stone & Webster, JBF Scientific, Jet Propulsion Laboratory, and Charles T. Main.

The new version of SYSGEN will be incorporated into the A model, a new long-range planning model being developed at MIT and sponsored by EPRI. This model will include time-dependent power plants as an alternative in capacity expansion.

4.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the SYSGEN Project)

Bloom, J., "Decomposition and Probabilistic Simulation in Electric Utility Planning Models," MIT Operations Research Center, Technical Report No. 154, August 1978. (PhD Thesis)

This paper develops a decomposition technique to solve long-range planning problems using SYSGEN as the non-linear operating constraint.

Bloom, J. and Finger, S., "Nonconventional Electric Power Sources in Long Range Planning," Forthcoming.

This paper describes a method for computing marginal capital and marginal operating costs for time-dependent power plants from SYSGEN.

Deaton, P.F., "Utility System Integration and Optimization," PhD Thesis, M.I.T., 1973.

This thesis contains a description of the original model, called PROSIM.

Finger, S., "Electric Power System Producting Costing and Reliability Analysis Including Hydro-Electric, Storage, And Time-Dependent Power Plants," MIT Energy Laboratory Technical Report No. MIT-EL 79-006, February 1979.

This paper describes the methodology used in SYSGEN 4, SCYLLA, and ELECTRA.

Finger, S., "SYSGEN, Production Costing and Reliability Model, User Documentation," MIT Energy Laboratory Technical Report No. MIT-EL 79-020, July 1979.

This paper provides detailed technical information on running SYSGEN, including input format and sample output.

Finger, S., "ELECTRA, Time-Dependent Electric Power Generation Operation Model, User Documentation," MIT Energy Laboratory Technical Report, No. MIT-EL 79-025, August 1979.

This paper provides detailed technical information on running ELECTRA, including input format and sample output.

Finger, S., "SCYLLA, Time-Dependent Electric Power Generation Evaluation Model," MIT Energy Laboratory Technical Report, Forthcoming.

5.1 MODEL HISTORY

a.	Name:	Analytical Models of the World Oil Market
b.	Developers:	M.A. Adelman, Department of Economics, Massachusetts Institute of Technology, Cambridge, Massachusetts Henry D. Jacoby, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts Robert S. Pindyck, Sloan School of Management, Massachusetts Institute of Technology, Cambridge, Massachusetts James Paddock, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c.	Duration:	1974-1980
d.	Location:	Massachusetts Institute of Technology, Cambridge, Massachusetts
e.	Sponsors:	The World Oil Project is being carried out by the Massachusetts Institute of Technology Energy Laboratory in assocation with the Sloan School of Management and the Department of Economics. The work was initiated in Summer 1973, with seed money from the MIT Energy Laboratory. Beginning in March 1975, the project received support from the National Science Foundation. Currently the research is also being supported, in part, by the MIT Center for Energy Policy Research.

5.2 MODEL DESCRIPTION

a. Summary

The objective of the World Oil Project is to develop improved methods and data for analysis of the future course of the world oil market over the next few decades. Market forecasts depend on analysis of likely demand for oil imports by major consuming countries, and the likely supply from exporters who behave as "price-takers" in their oil exploration and production decisions. The resulting net demand for oil from the core members of the oil cartel determines the ability of OPEC to set prices. The study of the net demand for cartel oil is accompanied by analysis of the likely behavior of the price-setters themselves (the cartel core), and exploration of the details of market structure as they influence price behavior and trade patterns.

This work involved development of a set of analytical models relating to oil supply from key producers, import demand from major consumers, and the integration of estimated supply and demand functions into a simulation model for studying future developments. The simulation framework is combined with a separate set of behavioral models of the cartel-core nations and their price-setting decisions, and with studies of evolving contract arrangements, trade patterns, and financial factors.

The basic approach to the analysis of the world oil market is shown in Figure 1 (see page 105). Figure 1 is a simplified flow diagram of the simulation model of the world oil market, and surveys the various analytical studies conducted under the project. However, it should be borne in mind that it is not a "world model" project; it is a project on the analysis of the world oil market. The work is eclectic in terms of the analytical structures used. The analytical models have used the best methods for the various parts of the problem; then an integrating framework has been used to tie them together. The integrating framework is of a fairly simple nature.

The heart of the project is the set of supply and demand models shown in the middle of Figure 1. These studies help to improve understanding the effects of fundamental market forces on energy demand and supply. In addition, these studies serve to provide estimates of supply functions for price-taker suppliers and demand functions for importers that are needed for the simulation model.

The simulation model itself is designed to accept an anticipated or assumed oil price trajectory, and to compute the resulting demands, supplies, and other market characteristics over a particular simulation horizon. The development of hypotheses about likely cartel pricing behavior represents another area of research conducted as part of this project. Several behavioral models of cartel pricing behavior have been developed, and the price hypotheses themselves are represented by the cloud at the upper left of Figure 1. It should be noted that the behavioral models of the cartel represent only one means of generating price scenarios; price scenarios based on independent analysis or judgment can also be tested.

The Analysis and Simulation of World Energy Demand

One part of the World Oil Project has been to develop a detailed econometric study of the world demand for energy. An important aspect of the study has been to develop and estimate models that better reveal the structure of energy demand, and help determine the long-run response of demand to changes in prices and levels of economic activity.

To understand world oil demand it is necessary to understand the demand for other fuels, since these fuels are all competitive. Thus, one objective has been to obtain a quantitative grasp on the characteristics of interfuel substitution in various sectors of energy use. Second, to better understand the characteristics of energy demand, a sector-by-sector analysis has been made of major consuming countries. In the case of the residential sector, for example, this means unerstanding the role of energy as a part of total consumption expenditures, and how energy might be susbtituted with other categories of consumption expenditures in response to price or income changes. In the case of the industrial sector, this involves analyzing the role of energy as a factor of production, and the degree of long-run substitutability between energy, capital, and labor. An indirect translog utility function has been used as a basis for modeling the residential demand for energy, and a translog cost function has been used as a basis for modeling the industrial demand for energy.

The regression analysis examines existing differences in residential and industrial sector uses of energy inputs and fuel shares of those inputs for a group of developed industrialized nations. These countries buy energy in a world market and sell products in a world market--which leads to the conclusion that the significantly different energy and fuel shares represented by different countries are compatible in the same overall market for energy, products, and lifestyles. We assume that any country can move towards the pattern of another country given time and appropriate price and income incentives. Therefore, the response to the recent history of large price rises is better understood by examining existing differences between countries rather than the post-World War II experience *within* countries, which involved gradual energy price decline and stable economic growth.

The econometric work on the residential and industrial sectors is based on an international time-series cross-section sample. Countries, the cross-sectional units, were allowed separate intercepts in the translog equations but were constrained to have identical slope coefficients. The elasticity estimates obtained from the regresssions primarily reflect the between-country differences as price changes were much larger there than over time within any one country. Such elasticities thus may be construed to be long-term equilibrium estimates rather than short-term transitional ones.

A different approach is used in the transportation sector. Demand for motor gasoline has been treated as a derived demand based on a set of estimated equations for the stock, use, and efficiency of automobiles. Analyzing gasoline demand in this way allows one to introduce and test different dynamic adjustments for each of the three component variables. The demand for motor gasoline is modeled for each primary and secondary use. The study indicates gasoline demand to be much more price-elastic in the long run than would be indicated by most earlier studies. As for the income elasticity of gasoline demand, the long-run values are close to most estimates of earlier studies.

Simple econometric models, largely logarithmic models with Koyck lag adjustments (i.e., with lagged dependent variable) have been used to model demand for petroleum products in other sectors and for the rest of the fuels used in the transportation sector. Although the econometric approach has been somewhat simpler, fairly robust estimates for price and income elasticities have been obtained. Price elasticities have been found to be larger than had been previously assumed and this has been attributed to the use of pooled international data to capture long-run effects.

In carrying out a demand simulation, a framework is needed for calculating consumer product prices as well as calculating the relationship of demand to those prices. The World Oil Demand Simulation Model is designed to take as standard policy inputs a forecast of the real price of Persian Gulf marker crude, and a forecast of the real GNP growth in the OECD countries.

The model uses these inputs to generate a forecast path for world oil demand. Therefore, a model had to be developed that translates exogenous Persian Gulf crude oil prices to prices for particular products in particular countries. The energy economy of the OECD countries has been modeled individually. The prices of energy inputs in the economy is determined by changes from a set of base prices for 1972. Changes in the Persian Gulf marker prices are passed on to the price of oil products in each of the countries. The price of other energy inputs is increased by the same percentage as that of oil products for a particular country. Other prices could change in real terms, but the general assumption is that they remain constant. These price changes are smoothed and then aggregated into an equivalent energy price for the residential and industrial sectors. This energy price, along with the prices of other consumption or other inputs and the income available to the sector determine consumption shares for the sector. The energy share for each sector is then disaggregated into shares of oil, gas, coal, and electricity. Diesel and remainder fuel consumption are determined by log-linear models with intercepts and cross-national and cross-income and price elasticities.

The five categories of demand--residential/commercial, industrial, and motor gasoline, diesel, and remainder--are added up and multiplied by factors to reflect refinery loss and bunker fuel, then converted to millions of barrels of crude equivalent daily. Finally, both the average price of an equivalent barrel and the government tax on an equivalent barrel are calculated.

The equation structure of the demand simulation is shown in Figures 2 and 3 (see pages 106 and 107).

The Analysis and Simulation of World Oil Supply

Two analytical methods have been developed: a disaggregated pool analysis and an aggregated country analysis. The disaggregated pool analysis is the more detailed of the models developed and requires the most data, geologic interpretation, and computational capacity. Though one method is far more ambitious than the other, essentially they are variations of the same approach, namely "process analysis." In other words, supply functions are based on a simulation of the process of exploration, development, and production within a petroleum region. Both take account of geologic data, though one has a more complex hypothesis about geologic deposition and the nature of the exploratory process. Both take account of economic factors such as costs and future petroleum prices, and both include an approximation of oil-developer decisions, though the aggregated method necessarily treats these in a highly summarized manner.

Figure 4 (see page 108) shows how the two analyses fit into a sequence of activities that compose the oil production decision process and the kind of statistics generated.

The Disaggregated Pool Analysis may be described in the following way: given enough wells drilled to furnish a reliable sample, and given geological knowledge to certify the existence of a population from which the sample is drawn, a forecast is made of the number of reservoirs to be found, and their size distribution. Given knowledge of costs, prices, and tax policies, one can make a forecast of the rate of exploratory drilling and the rate of development of the area. The disaggregated approach is shown in the left-half of Figure 4. The key variable is recoverable reserves, and here the method draws on research on statistical analysis of the exploratory process carried out by Kaufman and Barouch. The economic analysis of production is then applied to individual reservoirs. Development costs are estimated from the reservoir characteristics and applicable tax rules, and these are combined with an evaluation of revenues based on expected oil prices. Built into the analysis is a specification of the minimum economic reservoir size, and an evaluation of the likely production profile for reservoirs with different characteristics. The overall supply estimate for an area is the sum of the production profiles of individual reservoirs; and the overall supply from a country (or other region) is the aggregate of the results from the various areas distinguished for analysis.

The disaggregated pool analysis is a formal, precise, and reproducible version of what happens in industry every time a discovery is made. Estimates of probable reserves are changed, as are estimates of "ultimate" production. As development wells are drilled, providing new producing capacity and more detailed knowledge of reservoirs, the forecast of their production is crystallized into the industry's estimate of "proved reserves." The disaggregated method has been applied to the North Sea and analytical results have been applied in discussion of development policy questions in the area. The disaggregated method is costly in terms of its requirements of data, expert geological judgement, and computation time. Many of these needs preclude its application to many areas of the world.

The objective of "the Aggregate Supply Model" is to forecast crude oil production capacity by geographical area. The forecasting method is based on projections of development of rig activity and analysis of proved reserves added per rig year. Reserve additions then become an input to calculations of capacity expansion and likely oil production. The model is a simplified, inertial-process-type model based on "collapsed" versions of development expenditures and the associated production profile. This simple structure is designed to be applicable to all countries of the world, particularly those for which data problems exist, yet still capture the essence of the petroleum development and production process. The two key assmptions of the collapsing process are that all development investment is made at a single point in time and that maximum production begins at that same point, from which it declines over time. The optimal production path and the rate of development of reserves have been taken as a function of price per barrel, the interest rate, and the marginal capital cost. The forecasts of reserve development are therefore sensitive to oil prices as well as to costs and discount rates. However, it is an empirical fact that marginal capital cost estimates are nonexistent. Hence the best available estimate of "average cost at the margin" has been taken. The model registers discoveries and allows for their effects but, as yet, does not forecast them. The resulting investment level and ultimate output, given a forecast of the drilling rate, are only weakly responsive to price, given the severe cost data limitations. Work is underway to develop methods of forecasting the response of drilling to price, but at present the drilling scenarios are exogenous. The introduction of functions for endogenous drilling responses, however, should be done with care, for they do not necessarily generate additional drilling, and may often discourage drilling. Perverse price effects have been discerned in Norway, for example. The current model is basically inertial, projecting recent tendencies. It must be frequently updated, country by country, or field by field. As the data analysis work proceeds certain functional relations for drilling rates for those countries may prove responsive to price.

Reserves and production of crude oil for selected countries, (1975-1985) are shown in Table 1. [See Table 8, page 27, Jacoby and Adelman paper.]

Models of Cartel Behavior

A number of studies have been conducted on the structure of the OPEC cartel and its implications for the pricing of oil over the next two or three decades. In these studies, the cartel is treated as an economic unit. There are, of course, constraints within the cartel slowing down or blocking evolution, and also from outside macroeconomic or political factors. The importance of these behavioral models is that they show the ultimate tendencies of the group assuming wealth maximizing behavior.

This work has largely involved the application of nonlinear optimal control algorithms to several small and somewhat simplified models of the world oil market and the OPEC cartel. For example, in one study OPEC is treated as a unified monopoly that shares all production cutbacks evenly. A price trajectory has been determined for oil that would be optimal for the cartel and would maximize the sum of present and future discounted revenues. This optimization was subject to the constraints of a simple model of the world oil market, in which the total demand for oil was a dynamic function of price and income. The supply of noncartel oil was a function of price as well as resource depletion, and where OPEC's production costs would rise as its reserves were depleted. The model of OPEC has also been extended to account for the fact that some countries within the cartel operate under different objectives.

Work has also been done on fundamental questions in the economics of resource exploration and production. In particular, the problem of the interrelationship between the optimal rate of non-renewable resource exploration and the optimal rate of resource production has been examined.

Simulation Model:

As noted in the earlier section, a simulation model has been developed that incorporates the demand and supply models discussed above. It makes use of insights into OPEC behavior drawn from continuing studies of the behavior of the cartel case. The overall simulation apparatus consists of three parts:

- A demand simulator, which includes a set of price determination routines, and which computes worldwide demand using the equation structure summarized in Figure 3.
- A supply simulator, which implements the aggregate model of oil supply, summarized in the right side of Figure 4.
- A simple integration package which computes supply-demand balances and analyzes the allocation of excess capacity within the cartel.

The large-scale simulation model has gone through several stages. A sample of the simulation output is shown in Table 1 (see page 109). Assumptions behind this particular calculation are shown at the bottom of the table. In addition, consumer taxes are held constant in the sample result.

b. Data Base

The World Oil Project has developed two discrete data collections, one for supply and one for demand. Both data collections are described below, including information on the present storage format of each.

Demand Data Collection

The demand data collection consists of time series, generally covering the years 1955-1973. It is international in scope, concentrating on the major oil-consuming countries. The data collection is divided into 4 sections: residential energy demand data, industrial energy demand data, transportation sector demand data, and a section for demand by product. In addition to energy demand, variables relevant to the sector, such as end-user prices and economic activity indicators, are also included. The four sections are described briefly below.

Industrial Sector

The countries included in this section of the demand data base are:

Canada, France, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, U.S.A., and West Germany. Consumption and prices of fuels, the prices of capital and labor, asset price indices, purchasing power parities, and interest rates have been compiled. The characteristics of the time series are described below.

Fuel Consumption, Expenditures on Fuels, Prices

Industrial sector consumption of petroleum, coal, electricity, and gas were obtained from OECD *Energy Balances* for the years 1960-1974. These data series were related to those in earlier OECD publications via simple linear regressions, which were used to extrapolate the 1960-1974 series back to 1955. The units were converted to tcals. Industrial prices of these fuels were obtained from SOEEC publications, the FEA (DOE), and the Edison Electric Institute. These were converted to units of local currency/tcal. These series were then used to create time series on fuels expenditures, which were converted to units of millions of local currency.

Value-Added, and Expenditures on Capital and Labor

Data on value-added at factor cost was obtained from the United Nation's *Growth of World Industry*, and the *Annual Yearbook*, for eight of the ten countries. Value-added tax for France and West Germany was obtained from the SOEEC *Tax Yearbook* to calculate value-added at factor cost for those two countries.

Expenditure on labor, defined as wages, salaries, and supplements paid to the manufacturing sector, were collected for all countries. The sources used were the United Nations' *Growth of World Industry*, the ILO's *Statistical Yearbook*, United Nations' *National Accounts*, and national *statistical yearbooks*.

Expenditures on capital services were derived from value-added net of expenditure on labor. All data series are in units of millions of local currency.

Price of Labor and Capital

The price of labor was determined as:

$$\frac{\text{price}}{\text{hour}} = \frac{\text{expenditure or labor}}{\text{total man hours of employees}}$$

Data on man hours of employees was obtained from the United Nations' *Growth of World Industry*, OECD's *Labor Statistics*, and publications of *the International Labor Organization*.

A price of capital services was calculated separately for residential structures and producer durables, and these were aggregated using a Divisia index. The data required are time series on depreciation rates, interest rates (obtained from *International Financial Statistics*), asset price indices for producer durables and non-residential structures, (obtained from OECD or UN *National Accounts*), and purchasing power parities. All components of the price of capital are stored as part of the data collection.

Deflators

GDP indices, obtained from OECD National Accounts, were used as price deflators.

Residential Sector Demand Data

The countries included in this section are Belgium, Canada, France, Italy, the Netherlands, Norway, the United Kingdom, the United States, and West Germany. Data series were developed on private consumption expenditures, fuel prices, personal disposable income, population, and temperature.

Private Consumption Expenditure

Series were compiled for each of the nine countries on private consumption expenditures on food, durables, transporation and communication, clothing, and fuels. The sources used were the SOEEC, UN, or OECD National Accounts, and national statistical yearbooks.

Fuel Prices

Retail prices of the three fossil fuels and electricity were collected. The sources used were SOEEC publications, The Basic Petroleum Data Book, the UK Digest of Energy Statistics, the Economic Report of the President, and Norway's national statistical yearbooks. All prices were converted to local currency/tcal, then converted to U.S. 1970 dollars using purchasing power parities.

Personal Disposable Income, Population, Temperature

Population data, in millions, were obtained from the UN Demographic Yearbook. The temperature series are averages of the five coldest months, from the U.S. Weather Bureau's Monthly Climatic Data for the World. Personal disposable income was obtained from OECD National Accounts.

Transportation Sector Demand Data

The countries included in this section are: Belgium, Canada, France, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, the United States, and West Germany. The basic variables are vehicles in use, traffic volume, consumption of diesel fuel and gasoline, fuel prices and taxes, and a price index for automobiles.

Vehicles in Use, New Registrations, Traffic Volume

Data series for vehicles in use, the number of new registrations, and traffic volume for three classes of vehicles--passenger cars, buses, and goods vehicles--were obtained from a number of sources: World Road Statistics, United Nations Statistical Yearbook, Motor Industry in Great Britain, and Highway Statistics.

Diesel Fuel and Gasoline Series

Final internal consumption of diesel fuel and gasoline and vehicular consumption of these two fuels were obtained from OECD Energy Statistics and converted to tcals. Taxation of gasoline and diesel fuel was obtained from World Road Statistics. The data are expressed as a percentage of the retail price.

Price Indices

An index of private expenditures on personal transportation equipment was created using data available from the United Nations' National Accounts Yearbook. A price index for passenger vehicles was constructed using the expenditure index divided by the GDP price index.

Petroleum Product Demand Data

The product demand data are the result of an attempt to account for all petroleum consumption in the non-Communist countries. All petroleum products consumed are included for the years 1950-1973 or 1974, in addition to prices of fuels, economic activity indicators, temperature data, and purchasing power parities. The OECD countries are accounted for in the most detail, six non-OECD countries are dealt with in lesser detail, and the remainder of the non-Communist world is dealt with as aggregate regions.

Demand for Petroleum Products

For OECD countries, demand for 15 classes of petroleum products was obtained from OECD Energy Statistics. The United Nations' World Energy Supplies 1950-1974 was used for the rest of the world, although this publication only disaggregates petroleum products into four classes.

Deflators and Miscellaneous Time Series

GDP in current and constant currency was obtained from OECD National Accounts for OECD countries. For the remaining countries, United Nations' National Accounts was used. An implicit price deflator was created with these series. Population for all countries was obtained from United Nations publications. The average of the five coldest months was obtained from the American Meteorological Association's Monthly Climatic Data for the World.

Supply Data Collection

There are two data collections to support the supply analysis. One collection has production and reserve data for all major producing countries; the other has development of drilling costs for the U.S. and other countries.

Producing Countries: Production and Reserves Data

Data on production and reserves are included for all OPEC countries, both on and offshore, where relevant. The non-OPEC countries covered are: Norway, the United Kingdom, China, Malaysia-Brunei, the U.S.S.R., Australia (on and offshore), Argentina, Brazil (on and offshore), Mexico (Reforma and other), Canada, the U.S.A., and Alaska (included separately). The remainder of the world is treated as aggregate regions.

Cumulative Production

The cumulative production series reports the total amount of crude oil ever produced from an area up to December 31, 1975. The sources used were the *International Petroleum Encyclopedia*, year-end issues of the *Oil and Gas Journal*, and various oil companies. Units are in billion barrels.

Proved Reserves

This corresponds to the API definition. These estimates were obtained by dividing *International Petroleum Encyclopedia* reserves of identified largest fields by the portion of total country current production accounted for by those fields. However, if the figure for proved reserves as reported in the *Oil and Gas Journal* was lower, that was used instead. For Canada, the estimate of the Canadian Petroleum Association was used: for the U.S., the API estimate was used.

Cumulative Discoveries

This is the total of proved reserves plus cumulative production.

Ultimate Discoverable Reserves

This is the total of cumulative discoveries (above) plus probable additions plus expected discoveries. These last two are essentially subjective interpretations of limited data. The estimates used here were obtained from oil companies and a report delivered to the World Petroleum Congress, Tokyo, 1975; "An Estimate of the World's Recoverable Crude Oil Resources," by John Moody and R.W. Esser. *The International Petroleum Encyclopedia* and "Geographical Implications of Russian and Chinese Petroleum," in *Exploration and Economics of the Petroleum Industry*, Volume II, were also used.

Proved Reserves Added Per Rig Year

Proved reserves added per rig year were calculated with three methods, using data from the International Petroleum Encyclopedia and Hughes Tool Company Data both on total rig years and on proved reserves added were calculated by:

1) change in proved reserves method,

2) average flow-rate method, and

3) weighted flow rate.

The units are million barrels/rig year.

Drilling and Cost Data

United States

This data is for 39 producing regions of the U.S., and the total for the U.S.

Wells

Total cost of wells in dollars, number of wells drilled, average depth of the wells, and percentage of wells that were dry composed the data series collected for the period 1967-1977. The source of the data is the Joint Association Survey, Section 1: Drilling Costs.

Drilling Cost Index

A drilling cost index, 1974 = 100, for the years 1963-1978 was obtained from Independent Petroleum Cost Study Committee reports.

Rig Years

Average running rigs per year for 30 U.S. regions were obtained for the years 1967-1972, and for 37 regions for 1973-1977, from Hughes Tool Company information.

Cost Per Well

Cost per well in thousands of dollars and average depth per well for Louisiana offshore and South Louisiana were obtained from the Joint Association Survey. A breakdown of all exploration, development, and production costs for the total U.S. was obtained from the Joint Association Survey of the Oil and Gas Producing Industry, Section 2: Expenditures and Receipts.

International

Annual production in millions of barrels and number of producing wells for each major field for 1974-1977 were obtained from the International Petroleum Enycyclopedia, and the year-end issues of Oil and Gas Journal.

c. Computer Aspects

Programs currently exist for projecting capacity using the aggregate supply model, simulating a demand model, and performing an integration of the supply and demand projections. The three programs may be operated entirely independently. The three programs do not do the actual simulation and integration themselves; rather, they derive other TROLL functions or models. Though differing in specifics, the programs share the ability to interact with the user through relatively simple instructions.

The simulation program performs simulations of the aggregate supply model for any region for which data are available. The supply simulation program organizes input to and output from the aggregate supply program written in FORTRAN and accessible through TROLL. The demand simulation program takes as input certain parameters, then simulates the demand model to 1990. The integration program takes as input the files in which the supply and demand projections are stored. The simulation program is written in TROLL, with the supply analysis written in FORTRAN and imbedded in the TROLL structure.

A model simulator is currently being constructed as part of integrating the demand model with the W.O.P. modeling framework to facilitate access to the program. The command syntax is similar to standard TROLL commands and macros, and it makes available all the model modification capabilities in TROLL. This core program standardizes access to these facilities. It also provides on-line documentation, and on the printout; these features make it possible to reproduce any run made with the model. The command syntax makes availble a modifiable base of commands that are automatically implemented without explicit reference, plus an arbitrary number of user-designated command options.

The data described here were developed and are currently stored on the TROLL system. A TROLL account on the MIT IBM VM/370 is needed to access TROLL files. Approximately 12 disks are required to store the data. The supply data is stored in two-dimensional matrix format and some prior familiarity with both the nature of the data and TROLL is required to utilize the supply data. The demand data are usually stored in one-dimensional data files, with associated documenting comments. The use of the User's Guide (MIT-EL 78-016WP), which documents the data, and some familiarity with TROLL are necessary to access the demand data.

In addition to the on-line storage, data can be made available on magnetic tape, in either TROLL or standard FORTRAN-type format.

5.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The World Oil Project study is readily applicable to a number of policy questions. Several analyses, particularly simulations of oil market responses to various assumed scenarios, have been performed in response to the requests of government agencies and Congressional committees.

A number of special studies are being conducted on the world oil market:

- Contract Arrangements and Trade Patterns

  Work is continuing on the monitoring of developments in the oil markets; continuing research in this area is considered to be an essential component of further work on the world oil market.

- Analysis of Producer Tax Systems

  Preliminary work on the impact of North Sea fiscal regimes on oil supply has been undertaken.

- Further Development of the Disaggregated Model:

  The work related to this task has drawn the greatest concentration of effort and will continue to do so. The three major areas of research are: (i) disaggregated field analysis; (ii) endogenous development drilling rates; and (iii) drilling cost estimation and analysis.

  The disaggregated field analysis has mainly focused on the North Sea, Egypt, and Mexico. The analysis is modular in nature and the model gives a smooth and "believable" representation of the expected production patterns of fields already in use. The empirical work at the field level is also a step in the larger task of formulating a procedure that can disaggregate the estimate of new discoveries and producing units by field size.

  Theoretical work on endogenizing the drilling rate in the supply analysis has also been undertaken. A dynamic programing framework is used to derive the optimal path of development drilling as a function of prices and costs. The endogenous drilling concept will be incorporated into the Disaggregated Field Model when it is completed.

  Also, to support the larger task of disaggregated model development, a drilling cost analysis has been initiated. The purpose of the cost study is to develop the relationship between U.S. oil and gas costs and their determinants, then apply it to other areas in the world where exploration and development is or will be occurring, but where data are not available.

  Another proposed area of research is to integrate these various components into a new computer program for supply analysis.

- Incorporation of the Influence of Financial Factors on Supply

  Preliminary work on several areas related to the influence of financial effects on oil supply has been completed. The major objective is to develop an analysis that states explicitly the influence of financial considerations on the investment and production decisions of oil-producing countries. The design of a preliminary macro financial model for analysis of the behavior of exporters such as Venezuela and Mexico has been completed.

  On another aspect of the financing problem, an experimental study is being conducted with the use of the Capital Asset Pricing Model to study the cost of financing development investment in the North Sea.

- Portfolio and Supply Decisions by OPEC Countries

  In modeling the behavior of oil-exporting countries, oil policy is viewed as an asset management problem. The behavior of both the surplus and deficit oil-producing countries has become an increasingly deliberate exercise in portfolio selection under various constraints.

Also, over the next two years there will be a program of research, under NSF support, along the following lines:

- The design and implementation of the combined exploration/discovery and production analysis of oil supplies. This implies an improvement in the analysis of micro aspects of oil supply at the disaggregate level. It also is a necessary step in preparing a microeconomic framework that can be combined with financial aspects of the supply decision. Part of this preparation involves the development of better analytical methods and data for investment cost estimation by disaggregated pool size.

- Integration of the microeconomic analysis of supply with analysis of country finance.

Professors M.A. Adelman, Henry Jacoby, and research staff members James Paddock, James Smith, Mansoor Dailami, Wayne Christian, and Jacqueline D. Carson of MIT are actively engaged in the studies mentioned above.

5.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the World Oil Project)

Adelman, M.A., "Producers, Consumers, Multinationals: Problems in Analyzing a Non-Competitive Market," October 1977. Originally released as M.I.T. Energy Laboratory Working Paper No. MIT-EL 77-038WP, a revised version of this paper appeared as: "Constraints on the World Oil Monopoly Price," Resources and Energy, Vol. 1, No. 1, North Holland Publishing Company, Amsterdam, 1978. A summary appears in Petroleum Economist, September 1977.

The consuming nations have the power to damage or wreck the world oil monopoly, but they prefer cooperation because of their fixed belief that otherwise the market will fail to clear and generate a "gap." Yet they may use the power inadvertently. The monopoly acts essentially as a loose cartel, with a safety net: A large seller (Saudi Arabia) would, if need be, act as the restrictor of the last resort. But this would maximize Saudi profits at a much lower price, penalizing the other sellers. The conflict can be held off by ad hoc agreements when raising the price. But the risk of conflict and highly uncertain long-run demand and supply make it likely that the cartel will only slowly and gradually approach profit or wealth maximization. "Political objectives" coincide with economic and can be neglected.

Adelman, M.A., "World Supply and Demand," presented to the Canadian Society of Petroleum Geologists in Calgary, and to be published by the CSPG in a volume of 50th Anniversary Proceedings, forthcoming.

The energy gap or "shortage" is logical nonsense. An oil "price break" upwards is possible, but unlikely. There is an interrelated system of demand; supply potential; monopoly control by the OPEC nations; and effects of crude oil price changes on the world economy and on consumer-nations policies.

Some preliminary results of the MIT World Oil Project are: 1) slow consumption growth because of lower income growth, the delayed effects of higher prices in 1973-74, and future increases; 2) complex effects on supply of higher oil prices which, depending on government action, may increase or decrease investment and capacity; 3) excess capacity and also higher prices through the 1980s, unless the monopoly is unexpectedly destroyed; and 4) great uncertainty must be factored into the policies of business and government.

Adelman, M.A., and Jacoby, H.D., "Alternative Methods of Oil Supply Forecasting," in Advances in the Economics of Energy Resources, R.S. Pindyck (ed.), Vol. II, J.A.I. Press, 1979.

Analysis of likely developments in the world oil market is ultimately dependent on some method of forecasting oil supply from key regions. Unfortunately, data problems tend to dominate work in this area, and much of the analysis is reduced to making the best use of the limited information available. This paper reports on two alternative approaches to this forecasting problem, both data-oriented.

Petroleum exporters need to be grouped into two rough categories. First, there are what we call price-taker suppliers. Second, there is the "cartel core"--a small group of nations that are the price-makers. Their groupings are not hard and fast; indeed, an exporter would change from one to another camp.

This paper focuses on the price-takers. The analysis seeks to understand the fundamental market forces, and to provide estimates of supply functions for price-taker suppliers and demand functions for importers. These functions are to be incorporated into a simulation model of overall market performance.

Adelman, M.A. and Ward, G., "Estimation of Worldwide Production Costs for Oil and Gas," Advances in the Economics of Energy and Resources, Vol. III, J.A.I. Press, Spring 1980.

This paper summarizes the work the authors have been doing in the past year. The primary purpose is to describe and implement a methodology for estimating drilling and equipping costs of onshore and offshore wells using only the usual data available on such activities: rig time spent drilling and wells completed. The predominant technique used in estimating the various relationships was regression analysis, using less specific published articles and reports as checks.

A method of incorporating such non-drilling production costs as overhead is also proposed. Finally, the cost estimates are applied to obtain dollar requirements per daily barrel of production capacity for major oil-producing areas. Appendices are included on special problems associated with estimating offshore platform and pipeline costs; another appendix examines recent claims about Saudi Arabian production costs. The remaining appendices present North Sea production costs calculated using unusually detailed published information, and a rough check comparing the calculated production outlays with reported outlays.

Agmon, T., Lessard, D.R., and Paddock, J.S., "Financial Markets and the Adjustment to Higher Oil Prices," in Advances in the Economics of Energy and Resources, R.S. Pindyck (ed.), Volume I, J.A.I. Press, Greenwich, Conn., 1979.

This paper explores the linkages between the world energy and world financial markets. The role of international financial markets in the adjustment of the real markets for energy is analyzed from both a conceptual and an empirical viewpoint. Financial intermediation is found to be an important accommodation mechanism in the market-clearing behavior of price and quantity. Finally, we look at the portfolio aspects of producers' "surplus funds" and the implications of stress on the world financial market.

Cremer, J. and Weitzman, M.L., "OPEC and the Monopoly Price of World Oil," European Economic Review, Vol. 8, 1976.

This paper presents a dynamic model of the behavior of OPEC viewed as a monopolist sharing the world oil market with a competitive sector. The main conclusion is that the recent increase in the price of oil was a once-and-for-all phenomenon due to the formation of the cartel. The model form used here indicates that real oil prices should remain approximately constant over the next 20 years.

Dailami, M., "Inflation, Dollar Depreciation, and OPEC's Purchasing Power," The Journal of Energy and Development, Spring 1979.

The objective of this paper is to provide some empirical analysis of the impact of dollar's fluctuation on OPEC's terms of trade over the period 1971-1977, and to assess to what extent the decline in OPEC's terms of trade, after the fourfold oil price increase of late 1973, can be attributed to the falling value of the dollar and to the high rates of inflation prevailing in the industrial countries. The study is divided among a theoretical analysis of OPEC's terms of trade (the model), the empirical results, and a brief summary with some significant conclusions.

Dailami, M., "Financial Influences on the Behavior of Oil Exporters," Proceedings of the IAEE/REF Conference on International Energy Issues, forthcoming.

This paper discusses how short-term financial considerations may influence the oil production policies of oil-exporting countries, and concentrates on two countries: Venezuela and Saudi Arabia. In the case of Venezuela, a macro-financial model was constructed to analyze the effect of changes on oil revenues on CDP, money supply, goernment deficit, and government foreign debt. In this regard it was found that increases in the oil revenues will have a positive effect on all these variables. For instance, an incremental increase of 5 percent in oil revenues from 12.5 to 17.5 percent per year will raise the average annual rate of growth of GDP from 10 to 13 percent during the simulation period, i.e., 1978-1985. The model was then used to forecast likely oil exports of Venezuela. Different oil price and economic growth scenarios were used in forecasting oil exports.

In the case of Saudi Arabia, the analysis was conducted with a more simplified model. By concentrating on the external sector of Saudi Arabia's economy, the average daily oil production requirements for this country were derived using different scenarios of the real price of oil and different levels of imports. It was generally found that Saudi Arabia could cut its oil production in 1980 by about 1/3 of its current production and still plan for import volume growth of up to 30 percent per year in 1979. However, it will not be feasible to continue this policy of import growth to the mid-1980s, even at a steady oil production level of 9 million barrels per day. In fact, in 1985 Saudi Arabia's oil production requirements for import growth rates of even 25 percent per year in real terms would most likely be constrained by productive capacity limitations.

Eckbo, P.L., "A Basin Development Model of Oil Supply," in *Advances in the Economics of Energy and Resources*, Pindyck, R.S. (ed.), *Vol. II, J.A.I. Press, Greenwich, Conn., 1979.*

This paper describes a procedure for estimating the supply potential of a region given an exogenously specified time profile for exploratory drilling. The procedure involves analysis of the exploration for finding development and production of reservoirs. The Basin Development Model relies on a deterministic discovery sequence. This discovery decline relationship serves as a first approximation to the joint analysis of the exploration for plays and reservoirs inside a play. The reservoirs found enter into a reservoir model that takes account of costs and unexpected future prices, and allows detailed consideration of the tax regime. By separating exploration and finding activities from development and production activities, the Basin Development Model allows consideration of the two major aspects of resource depletion: the depletion of producible reservoirs from the population of reservoirs to be found, and the depletion of recoverable reserves from the existing population of producible reservoirs. The price elasticity of the level of ultimate recoverable reserves falls out of the interaction between the exploration and reservoir analysis, as demonstrated in the paper.

Eckbo, P.L., Jacoby, H.D., and Smith, J.L., "Oil Supply Forecasting: A Disaggregated Process Approach," *Bell Journal of Economics*, Spring 1978.

Work is underway on a forecasting method that incorporates explicit representations of the steps in the oil supply process: exploration, reservoir development, and production. The discovery history of a region and other geological data are input to a statistical analysis of the exploratory process. The resulting estimate of the size distribution of new reservoirs is combined with an evaluation of reservoir economics--taking into account engineering cost, oil price, and taxes. The model produces a forecast of additions to the productive reserve base and of oil supply. Progress to date is demonstrated in an application to the North Sea.

Eckbo, P.L., "Planning and Regulation in the North Sea," *Northern Offshore*, No. 9, September 1976.

This article discusses the impact of Norwegian Government block-allocation and tax policies on North Sea exploration, production, and reserve levels.

Eckbo, P.L., The Future of World Oil, Ballinger Publishing Company, 1976.

This paper describes a behavioral model of the international petroleum market and presents the results from it. The purpose of the study is to develop a framework for analysis of the implications of non-competitive behavior in the international petroleum market. The focus is on the market strategies that may be pursued by the world's oil exporters on either a joint or an individual basis. The structure of the model is designed to combine features of formal modeling and of informal "story-telling" in a consistent framework. Such a structure requires a simulation-type model.

The "stories" that are being told are constructed from cartel theory, from the empirical evidence on previous commodity cartels, and from the special characteristics of the individual oil exporters. The model is evolutionary in the sense that each exporter is assumed to behave according to a set of decision rules that may reflect a competitive market structure, a monopolistic market structure, or a combination of the two. Changes in the decision rules being applied provide for the evolution of the market price. An attempt has been made to combine formal competitive and monopoly models with those of the informal story-telling apprroach.

Eckbo, P.L. and Smith, J.L., "Needed Exploration Activity Offshore Norway," Northern Offshore, August 1976.

This article analyzes the linkages between North Sea Block allocations and their effect on future production. A statistical model is developed to explore the methodology by which Norway influences attainment of its target production rate by allocating blocks to producers.

Hnyilicza, E. and Pindyck, R.S., "Pricing Policies for a Two-Part Exhaustible Resource Cartel: The Case of OPEC," European Economic Review, Vol. 8, 1976, pp. 139-154.

This paper examines pricing policies for OPEC under the assumption that the cartel is composed of a block of spender countries with large cash needs and a block of saver countries with little immediate need for cash and a lower rate of discount. The decision problem for the two-part cartel is embodied in a game-theoretic framework and the optimal bargaining solution is computed using results from the theory of cooperative games developed by Nash. The set of feasible bargaining points--and the corresponding Nash solution--is computed under two assumptions of the behavior of output shares: that they are subject to choice and that they are fixed at historical values. The results suggest that, for fixed output shares, there is little room for bargaining and the price path approximates the optimal monopoly path. If the shares are subject to control, optimal paths depend significantly on the relative bargaining power of each block.

Jacoby, H.D., "MIT World Oil Project," in Proceedings of the Workshop on World Oil Supply-Demand Analysis, Hoffman, K.C. (ed.), June 1-2, 1977, Brookhaven National Laboratory, October 1978.

This paper describes the structure of the project, methods being used, and problems of data and analysis.

Jacoby, H.D., "The Oil Price 'Ratchet' and U.S. Energy Policy," Kokusai Shigen (International Resources), Tokyo, Fall 1979.

This is an analysis and interpretation of events in the world oil market during 1979. OPEC behavior is described in terms of a "ratchet" method of price administration, whereby capacity is held tight, spot prices surge upwards, and official contract prices follow thereafter. The implications for U.S. policy are discussed.

Jacoby, H.D. and Paddock, J.L., "Supply Instability and Oil Market Behavior," Prepared for the IAEE/RFF Conference on International Energy Issues, to be published in Energy Systems and Policy, forthcoming.

This paper analyzes the supply disruption in the world oil markets in the winter of 1978-1979. The causes of the resulting price rises are explored in the context of spot market behavior and cartel core behavior. In particular, the economic and political roles of excess supply in the Persian Gulf nations are discussed, and conclusions for the likely future are presented. Finally, the implications for U.S. policy of these conclusions are discussed.

Pindyck, R.S., The Structure of World Energy Demand, MIT Press, Cambridge, Massachusetts, March 1979.

This book provides a detailed description of the work done on world energy demand. The book begins with a discussion of the structure of energy demand, then describes the specification of alternative demand models for each sector of energy use. Next, a number of methodological issues involved in the estimation of energy demand models is discussed in detail. Statistical results are presented for energy demand models pertaining to each sector of use. Finally, the book discusses the macro-economic impact of higher energy prices in the industrialized countries, and the likely future evolution of the world energy market.

Pindyck, R.S., "The Characteristics of the Demand for Energy," in Energy Conservation and Public Policy, John Sawhill (ed)., Prentice-Hall, 1979.

This paper discusses the characteristics of energy demand and the likely impact of changing energy prices on aggregate energy demand and the demands for individual fuels. The paper also provides a survey of statistical studies of energy demand elasticities done over the last few years.

Pindyck, R.S., "OPEC's Dilemma: How To Control Production Levels," The Wall Street Journal, December 13, 1978.

A layman's summary report of an OPEC pricing/production behavior model, focusing on price forecasts.

Pindyck, R.S., "Optimal Exploration and Production of a Nonrenewable Resource," Journal of Political Economy, October 1978.

Most studies of nonrenewable resource production and pricing assume there is a fixed reserve base to be exploited over time, but in fact with economic incentives reserves can be increased. Here we treat the reserve base as the basis for production, and exploratory activity as the means of increasing or maintaining reserves. "Potential reserves" are unlimited, but as depletion ensues, given amounts of exploratory activity result in even smaller discoveries. Given these constraints, resource producers must simultaneously determine their optimal rates of exploratory activity and production. This problem is solved for competitive and monopolistic markets, and shows that if the initial reserve endowment is small, the price profit will be U-shaped; production will at first increase as reserves are developed; later, production will decline as both exploratory activity and the discovery rate fall.

Pindyck, R.S., "OPEC's Threat to the West," Foreign Policy, Spring 1978.

This paper examines three important issues in international energy markets, and the implications for American energy and economic policy. First, the paper considers the likely pricing behavior of the OPEC cartel, and argues that OPEC is most likely to set the price of oil at the optimal level, i.e., the level that maximizes the sum of present and future discounted revenues. Some predictions regarding OPEC pricing are offered, and the implications for world energy markets are considered. We argue that the kind of crisis that has been of concern to the CIA--namely, a major shortage of oil beginning around 1982--is extremely unlikely to occur, and instead we need to be more concerned with the possibility of an embargo in the short term. Finally, the implications of higher energy prices for GNP growth, unemployment, an inflation in the industrialized countries are discussed. The paper concludes with a set of energy and economic policy recommendations.

Pindyck, R.S., "Gains to Producers from the Cartelization of Exhaustible Resources," The Review of Economics and Statistics, May 1978.

The potential gains to producers from the cartelization of the world petroleum, copper, and bauxite markets are calculated under the assumption of optimal dynamic monopoly pricing of an exhaustible resource. Small quantitative models for the markets for each resource are developed that acount for lag adjustments in demand and supply as well as long-term resource depletion. Potential gains from the cartelization of each resource are measured by calculating optimal price trajectories under competition and under cartelization, and comparing the sums of discounted profits resulting from each.

Pindyck, R.S., "Cartel Pricing and the Structure of the World Bauxite Market," Bell Journal of Economics, Autumn 1977.

A cartel is unstable if one or more of its members can earn higher revenues in the long run by undercutting the cartel price and expanding production. In this paper dynamic and static models of the world bauxite market are used to assess the stability of the International Bauxite Association, to suggest possible changes in its configuration, and to determine the likely impact of the cartel on the structure of the bauxite market and the future of bauxite prices.

Adelman, M.A., "Energy-Income Coefficients: Their Use and Abuse," MIT Energy Laboratory Working Paper No. MIT-EL 79-024WP, May 1979, to be published in Energy Economics.

The right way to estimate and forecast demand is to break consumption into rational subgroups, each analyzed to separate out effects of income, price, technology, etc. Two widely quoted relations between aggregate energy consumption and national income are used as a check on such an estimate: the average energy-income coefficient and the incremental energy-income coefficient. The average coefficient is a valid if imprecise measure, but the incremental coefficient should not be used at all; it mixes up four elements. These four elements are: the consumption-income relationship, the consumption-price relationship, the time needed to adjust to price change, and the rate of economic growth.

Adelman, M.A., "The Clumsy Cartel," MIT Energy Laboratory Working Paper No. MIT-EL 79-036WP, June 1979, to be published in the first issue of Energy Journal.

The price explosions in the world oil market result from the tardy recognition of the post-1973 consumption slowdown. Such odd results could not happen in a competitive market, but they are not at all strange in the world cartel. Despite stagnant demand and forecasts that it will continue to grow at present rates, OPEC has raised the price toward the optimal, and cut back expansion plans. The cartel is becoming clumsy, however, in its attempt to control the market. Formerly, they set the price, and allocation of output was left to the oil companies. Today, main producing countries set production themselves, independent of consumer demand by type and location. This results in large discrepancies, triggers speculation, and subsequently exaggerates resulting price movements. The Saudis and their neighbors are fine-tuning a cartel with coarse instruments. Supply has to be kept tight despite panic, hoarding, and spot-price gyrations, because the controllers fear losing control. They will avoid the dangerous surplus of supply and so keep prices under pressure.

Adelman, M.A., "The Political Economy of the Middle East--Changes and Prospects Since 1973," MIT Energy Laboratory Working Paper No. MIT-EL 79-037WP, June 1979.

Economic relations of the U.S. and the Middle East are dominated by the production and export of petroleum. This paper first looks at our "non-problems," or our belief in certain fictions that prevent us from investigating the real nature of our problems. Among these fictions are: the shortage or "gap" between oil supply and demand and panic about an "energy crisis," the political problem of "access" and "assurance of supply," and the U.S.-Saudi "special relationship." The real problem is price. This is discussed in the context of world oil supply and demand forecasts, world economic growth, communist sector exports, the strategies and problems of the cartel, the world recession-stagnation of 1974-75, and appropriate options for the U.S.

Adelman, M.A. and Jacoby, H.D., "Oil Prices, Gaps, and Economic Growth," MIT Energy Laboratory Working Paper No. MIT-EL 79-008WP, May 1978.

This paper uses the analytical results of the World Oil Project as a basis for discussion of likely events in the oil market in the 1980s.

Adelman, M.A. and Paddock, J.L., "An Aggregate Model of Petroleum Production Capacity and Supply Forecasting," MIT Energy Laboratory Working Paper No. MIT-EL 79-005WP, revised July 1979.

This paper presents a complete discussion and documentation of the MIT World Oil Project Aggregate Supply Model. First, the theoretical development and methodology are presented. The relationships between geologic and economic characteristics are analyzed and a system of equations representing the inertial process model is desired.

Next, the construction of the data is described and the data, by country segment, are presented in detail. Methods of bridging the many gaps in the data are discussed.

Finally, the simulation forecasts of the model are presented through 1990.

Agmon, T., Lessard, D.R., and Paddock, J.L., "Accommodation in International Capital Markets: Paying for Oil, Financing Oil and the Recycling of Oil Funds," MIT Energy Laboratory Working Paper No. MIT-EL 76-010WP, April 1976.

This paper focuses on the accommodation role served by the international financial markets in facilitating world oil market equilibration. The specific roles of primary and secondary recycling of oil funds are analyzed in the international adjustment process. An extensive empirical study is then conducted using data for 1973, 1974, and early 1975. This study reveals the magnitudes and important interrelationships between flows in the markets for goods and financial assets. The conclusion is made with a general equilibrium model that derives the supply behavior of an oil-producing country.

Agmon, T., Lessard, D.R., and Paddock, J.L., "The International Finance Aspects of OPEC: An Informational Note," MIT Energy Laboratory Working Paper No. MIT-EL 76-005WP, March 1976.

The purpose of this paper is to set forth the relevant questions and problems confronted by the world's capital markets due to structural changes in the world oil market. It presents a summary description of several financial aspects of OPEC, including the organization of relevant information and data into a form useful for subsequent analysis. A brief analysis of this information is included, but the main purpose is to collect and present the information in a systematic way, including sources.

First, it presents an analysis of the many forecasts of OPEC accumulated financial surpluses and their estimated investment disposition--with particular focus on the U.S., U.K., and Euromarkets. There follows a brief discussion and extensive source listing of the various financial proposals that arose to deal with these financial surpluses. Concluding sections present a chronology of the major international financial events that led up to the 1973 price rise and thereafter, and a summary of the subsequent changes in U.S. corporate tax policy.

Beall, A.O., "Dynamics of Petroleum Industry Investment in the North Sea," MIT Energy Laboratory Working Paper No. MIT-EL 76-007WP, June 1976.

The purpose of this study is to assess the economic potential of petroleum fields of the North Sea, as reflected in financial flows to the operating companies and host governments. Financial flows include future streams of exploration and development investment expenditures, and sales and tax revenues that accrue in the private and public sectors.

A prerequisite for the economic analysis is an evaluation of current petroleum potential of prospective North Sea Acreage, conducted at a disaggregated (pool) level. This part of the study relies heavily on geological insight and judgmental analysis provided by the author, as well as on published information and formal analytical methods.

The level of cash flows associated with the estimated resource potential is shown to depend on host government tax and investment policies, the world price of crude oil, and current industry perceptions of the profitability of individual fields.

Bradley, P., "Production of Depleting Resources: A Cost-Curve Approach," MIT Energy Laboratory Working Paper No. MIT-EL 79-040WP, June 1979.

The current energy situation has riveted attention on extractive resources--petroleum, uranium, and coal--and economists have become increasingly concerned with supply analysis for these commodities. Theory cannot ignore salient factors affecting production if observed prices and outputs are to be explained. This paper formulates the analysis of resource production through the use of cost curves to explain firm and industry output. The aim is to retain the descriptive power of this traditional mode of analysis. It is necessary, of course, to modify the calculation of costs to take account of limitations imposed by nature on resource output.

Definitions are presented for long-run average and marginal costs where both production volume and production rate are explicitly taken into account. Corresponding cost curves are illustrated for the simplest situation--uniform output until resource exhaustion. Section III of the paper illustrates derivation of cost curves for a more complicated case--declining output over time with shutdown occurring before the resource is entirely used. Section IV of the paper uses the cost-curve method of presentation to consider a familiar question in resource development: How does the interest rate affect rate of use? In the concluding section some cautionary notes are raised concerning application of this type of analysis, in particular with respect to the validity of the present-value maximization possible.

Carson, J., "A User's Guide to the World Oil Project Demand Data Base," MIT Energy Laboratory Working Paper No. MIT-EL 78-016WP, August 1978.

This guide provides a description of all data used for demand analysis in the World Oil Project. It cites sources used, range of years available, and provides a description of all conversions, aggregations, and other standardization of units. An index of computerized data files and information on how to access the computerized data or obtain the information in other formats are also included. Purchasing power parities and issues involving energy unit conversion are discussed.

Crandall, M.S., "The Economics of Iranian Oil," MIT Energy Laboratory Working Paper No. MIT-EL 73-003WP, March 1975.

This paper presents an analysis of the production pattern and development cost structure of the Iranian "Consortium" oil fields.

Production capacity of existing fields under alternative development technologies (e.g., water and gas injection systems) is analyzed first. This includes capacity maintenance and growth plans. The paper then presents a comparative cost study for these fields and derives per-barrel capital costs and present worth of each field.

The paper next reviews Iran's potential new fields and performs a similar production/cost study based on the published series of "Look Ahead and Capital Development Plans" through 1978 as issued by both the Iranian government (through its National Iranian Oil Company) and the Oil Service Company of Iran (OSCO--a private company owned by the former Consortium companies).

Dailami, M., "The Determination and Control of Money Supply in an Oil Exporting Country: The Iranian Experience," MIT Energy Laboratory Working Paper No. MIT-EL 78-027WP, July 1978, revised February 1979.

The impact on the economies of the oil-importing nations of the late 1973 oil price increase and its consequent international payment imbalances have been the subject of a great deal of research. But relatively little emphasis has been placed on the severe problems that the resulting capital inflows have created from the economies of oil-exporting countries. Most of these countries have experienced severe inflation and economic disparities since 1974. A better understanding of the role of oil revenues on the domestic economy of these countries can provide useful guidelines for better management of these economies and as a result provide more stability in the world oil market.

The objective of this paper is to analyze the role of oil revenues in the determination and the controllability of money supply in Iran. In particular, it pursues the double objectives of analyzing the degree to which the Central Bank has been able to influence the determination of money supply and the types of monetary instruments used in its effort to control money supply. Any change in oil revenues will change the foreign reserves holding of the Central Bank and at the same time, given the level of government expenditure, will affect the claims of the Central Bank on the government. This dual feature of oil revenues in Iran seems to us to be a key element in understanding the mechanism of the money base determination and hence has constituted the core of our theoretical analysis.

Dailami, M., "Measuring the Purchasing Power of Major Currencies from OPEC's Viewpoint," MIT Energy Laboratory Working Paper No. MIT-EL 79-033WP, February 1979.

With the price of oil quoted in terms of the U.S. dollar and with the dollar fluctuating differently with respect to different currencies, the question has emerged of how to measure the fluctuations in the value of the dollar in a way that is relevant to OPEC's economic interest and is theoretically meaningful. Related to this is the question of devising an appropriate standard of value for measuring the real rate of return obtained on OPEC's financial surpluses. Concern over these two questions has recently heightened, partly because of the large and continuous depreciation of the dollar since the beginning of 1977, with its implication for the real price of oil, and partly because of the need for some indices of value to be used by oil-producing countries in evaluating their options of choosing between "oil-in-ground and money-in-bank." The problem of comparing these two options is particularly keen to surplus-oil-producing countries such as Saudi Arabia and Kuwait, which are compelled to invest a relatively high proportion of their oil revenues in foreign financial assets.

Dailami, M., "The Choice of an Optimal Currency for Denominating the Price of Oil," MIT Energy Laboratory Working Paper No. MIT-EL 78-026WP, October 1978 (revised February 1979).

Recently much concern has been expressed about the impact of the dollar depreciation on the real export earnings of OPEC and the implications of any protective action taken by OPEC on world economic conditions and the future stability of the dollar. With approximately 80 percent of OPEC imports originating outside the United States and with a predominantly large proportion of OPEC's past accumulated surpluses invested in dollar-denominated assets, the loss incurred as the result of dollar depreciation appears to be substantial. Moreover this loss will be heavier in the future if the historical trend of OPEC's trade shares with the strong currency countries such as Japan and Germany continues its upward momentum.

To protect its export earnings, OPEC can, in principle, either change the dollar price of oil or shift from its existing dollar-oil pricing system to a system based on a currency basket. The objective of this paper is to analyze the impact of the dollar fluctuation on the purchasing power of OPEC's oil revenues and to identify some of the major problems facing OPEC in its attempt to substitute any other currency or a "basket of currencies" for the dollar.

Eckbo, P.L., "The Supply of North Sea Oil," MIT Energy Laboratory Working Paper No. MIT-EL 77-015WP, July 1977.

This paper discusses reserves and production estimates for oil reservoirs in the North Sea already in the production or development stage, are for reservoirs recently discovered and likely to enter the development stage, as well as for reservoirs likely to be discovered.

The statistical version of a disaggregated process model is used to analyze "drilling up" scenarios for the North Sea. The significance of the tail of the discovery decline curve when analyzing the long-term elasticity of oil supply with respect to price is thereby demonstrated.

Eckbo, P.L., "OPEC and the Experience of Previous International Commodity Cartels," MIT Energy Laboratory Working Paper No. MIT-EL 75-008WP, August 1975.

This study presents a review and analysis of the available literature of the history of international commodity cartels. Evidence was gathered on 51 cartel agreements in 18 industries. Cartel "success" was defined in terms of the ability of the organization to raise the price to at least two times the unit cost of production and distribution. Of the 51 cartel organizations reported in the literature, 19 achieved price controls that raised the level of charges to consumers significantly above what they would have been in the absence of collusive agreements.

The experience of these previous cartels shows that few were able to survive for very long. Those that did succeed in raising prices for four years or more were characterized by markets where the concentration of production was high, the demands inelastic, and the cartel's market share was high, and the membership had cost advantages over outsiders. In addition a characteristic of the successful cartels was that governments were not directly involved in their operatons. The paper attempts to draw conclusions about the future of OPEC based on its characteristics in comparison to those of successful and unsuccessful cartels in the past.

Heide, R., "Log-Linear Models of Petroleum Product Demand: An International Study," MIT Energy Laboratory Working Paper No. MIT-EL 79-006WP, February 1979.

This paper provides preliminary results on the estimation of petroleum product demand for major oil-consuming countries and final results for several countries whose oil consumption is less significant. More sophisticated models used to analyze the major countries' consumption have been developed elsewhere (Pindyck, etc.). The model specifications were simple log-linear, wherein the variables, price of the particular petroleum product, per capita GDP, and lagged per capita consumption of the petroleum products were used to explain per capita consumption of the product.

Heide, R., "The Demand for Motor Gasoline: A Multi-Country Stock Adjustment Model," MIT Energy Laboratory Working Paper MIT-EL 79-057WP, April 1979.

The demand for motor gasoline is a large component of total demand for oil in industrial countries. This paper describes the development and testing of a dynamic gasoline model using a capital stock model for 11 major countries. The underlying assumption is that gasoline demand is derived from distinct consumer decisions, such as gasoline price, income, and available automobile stock. Automobile stock, distance, and efficiency adjustments are all posted to take more than one period; the dynamics thus arise from this adjustment behavior.

Jacoby, H.D., et al., "Energy Policy and the Oil Problem: A Review of Current Issues," MIT Energy Laboratory working Paper No. MIT-EL 79-046WP, September 1979.

This is a review and evaluation of oil-related energy policy issues under consideration by the U.S. Congress in fall, 1979. It covers oil import controls, security measures, oil decontrol and excess profits taxation, synfuels programs, and the Energy Mobilization Board. To set the stage for analysis of specific proposals, there is a discussion of the energy problem and its origins in the world oil market, with a particular focus on security aspects of the oil situation and the likely gains from oil import reduction as compared with other security measures.

The study was sponsored by the MIT Center for Energy Policy Research, but made substantial use of data and analysis resulting from the MIT World Oil Project.

Members of the MIT World Oil Project, "Progress Report to the National Science Foundation for Project on Cartel Behavior and Exhaustible Resource Supply: A Case Study of the World Oil Market--7/1/78 through 6/30/79," September 1979.

This report covers the first year of support under NSF Grant No. DAR-78-19044. It describes research on disaggregated methods of analysis of oil supply, including tax and financial aspects and analysis of cartel behavior. It also reports on the continuing process of documentation and use of analysis methods developed earlier in the project.

Pindyck, R.S., "Energy Demand and Energy Policy: What Have We Learned," presented at the International Scientific Forum on an Acceptable World Energy Future, Miami, Florida, November 30, 1978 (to be published by ISF).

This paper is a survey of about 30 recent econometric studies of energy demand, including the international study of world energy demand done by the MIT World Oil Project. The paper argues that there is much more of a consensus than one might infer from a casual scanning of the recent statistical evidence. Differences in elasticity estimates by various researchers can in large part be attributed to model structure and the nature of the data used. We argue that there is no growing evidence that in the long term price elasticities of demand are significantly larger than we thought to be the case earlier. The paper also discusses the implications of this point for the formulation of energy policy.

Pindyck, R.S., "Some Long-Term Problems in OPEC Oil Pricing," MIT Energy Laboratory Working Paper No. MIT-EL 78-038WP, December 1978.

This paper deals with two long-term issues in OPEC oil pricing. First, to what extent can a changing allocation of production cutbacks, in which a growing burden is placed on Saudi Arabia and a few other countries while other cartel members behave essentially as price takers, tend to erode the monopoly price over the next 20 years? Second, to what extent would the emergence of Mexico as a significant producer of oil reduce the monopoly power of the cartel and reduce the cartel price?

Both these questions are dealt with using the small monopolistic model of optimal cartel pricing.

Pindyck, R.S., "Interfuel Substitution and the Industrial Demand for Energy: An International Comparison," Review of Economics and Statistics, May 1977. Also published as MIT Energy Laboratory Working Paper No. MIT-EL 77-026WP, August 1977.

This paper describes the specification and estimation of some alternative models of energy demand for the industrial sectors of a number of industrialized countries. All the models are based on a two-stage determination of energy expenditures. The first stage of each model determines the fraction of the cost of production allocated to energy, as opposed to such other factor inputs as capital and labor. In the second stage, energy expenditures are allocated to different fuels.

The most promising results came from the use of a two-stage translog cost function as a description of the production process. The advantage of this translog function is that it is a general approximation to any cost function, and therefore does not a priori impose constraints of homotheticity or separability on the structure of production. These functions were estimated using pooled data for 10 countries. Other models, including static and dynamic logit models, were also treated. Results from this study seem to indicate that price elasticities for industrial energy demand are larger than had been thought earlier, and that in the long run there may be substitutability between energy and capital. The own price elasticity for total industrial energy demand was estimated to be about -0.8.

Pindyck, R.S., "International Comparisons of the Residential Demand for Energy," MIT Energy Laboratory Working Paper No. MIT-EL 77-027WP, August 1977. This is an updated version of MIT-EL 76-923WP.

This paper describes alternative models of energy demand in the residential sectors of a number of industrial countries. The models are based on a two-stage determination of energy expenditures. The first stage of each model determines what fraction of consumers' total budgets will be spent on energy, as opposed to such other consumption categories as food, clothing, etc. In the second stage, energy expenditures are allocated to alternative fuels.

The most promising results came from the use of a two-stage indirect translog utility function. The advantage of the translog function is that it is a general approximation of any utility function and therefore does not a priori impose constraints of homotheticity, separability, or additivity on the structure of demands. These functions were estimated using pooled data for nine countries. Other models, including the logit model, were also tested. Results from this study seem to indicate that price elasticities for energy demand are larger than had been thought earlier. The own price elasticity for total energy demand was estimated to be about -.9.

Supply Working Group, MIT World Oil Project, "Supply Forecasting Using Disaggregated Pool Analysis," MIT Energy Laboratory Working Paper No. MIT-EL 76-009WP, May 1976.

This study develops and illustrates a methodology for forecasting additions to reserves and production in a relatively young petroleum province. Components of the analytical method include an exploration process submodel that predicts that arrival and size of new discoveries and a reservoir development submodel that determines the rate at which discovered resources become available as economic reserves.

Both submodels emphasize the influence of such economic variables as oil price, development costs, and government taxes on the rate and pattern of resource exploitation. Consequently, the analytical framework neatly accommodates policy simulations that arise from varied economic scenarios.

Implementation of the forecast methodology is demonstrated for the North Sea petroleum province. Projection of future additions to reserves and annual production are carried out in detail, to reveal both the flexibility and the limitations of the analyticl procedure in its present form.

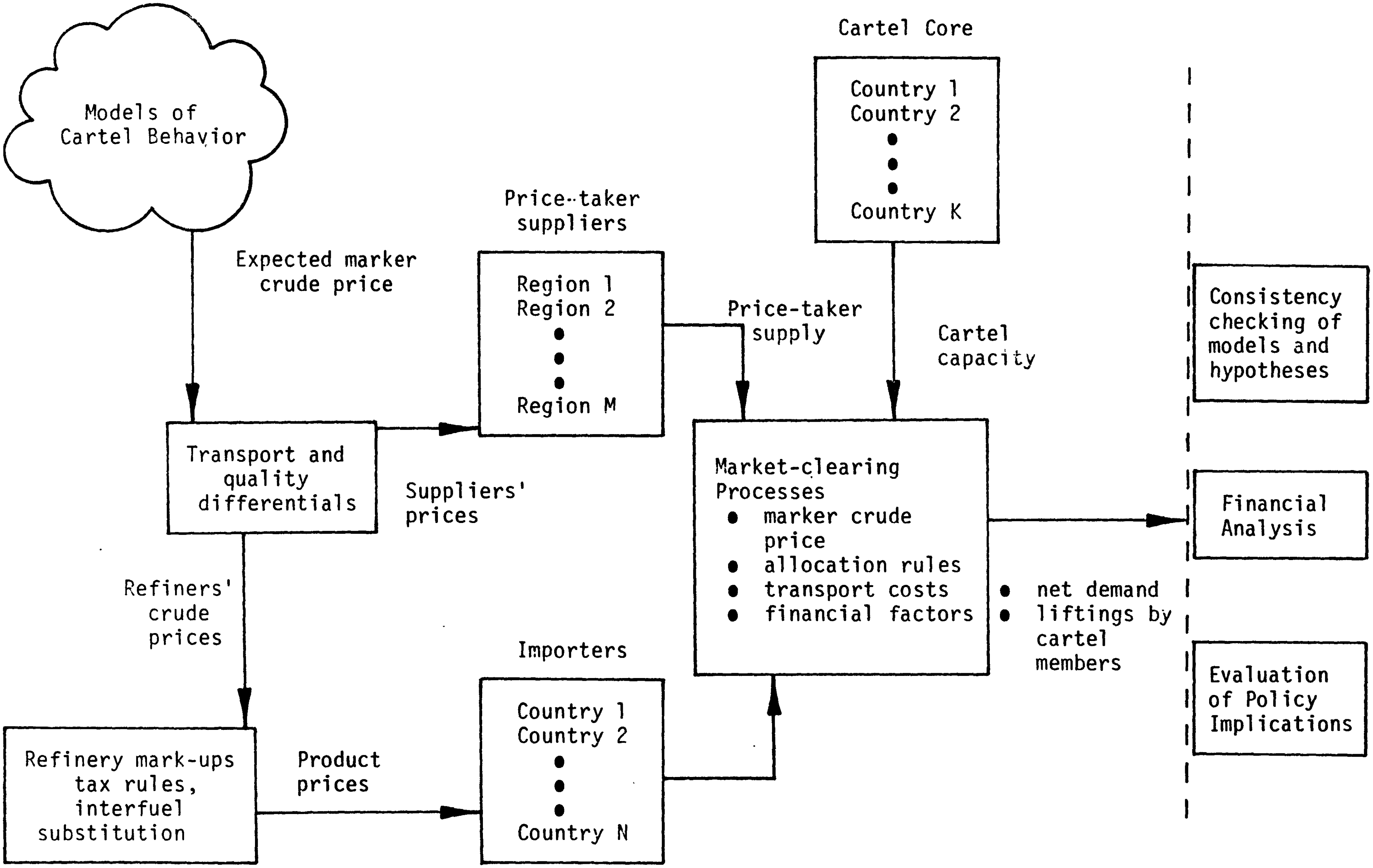
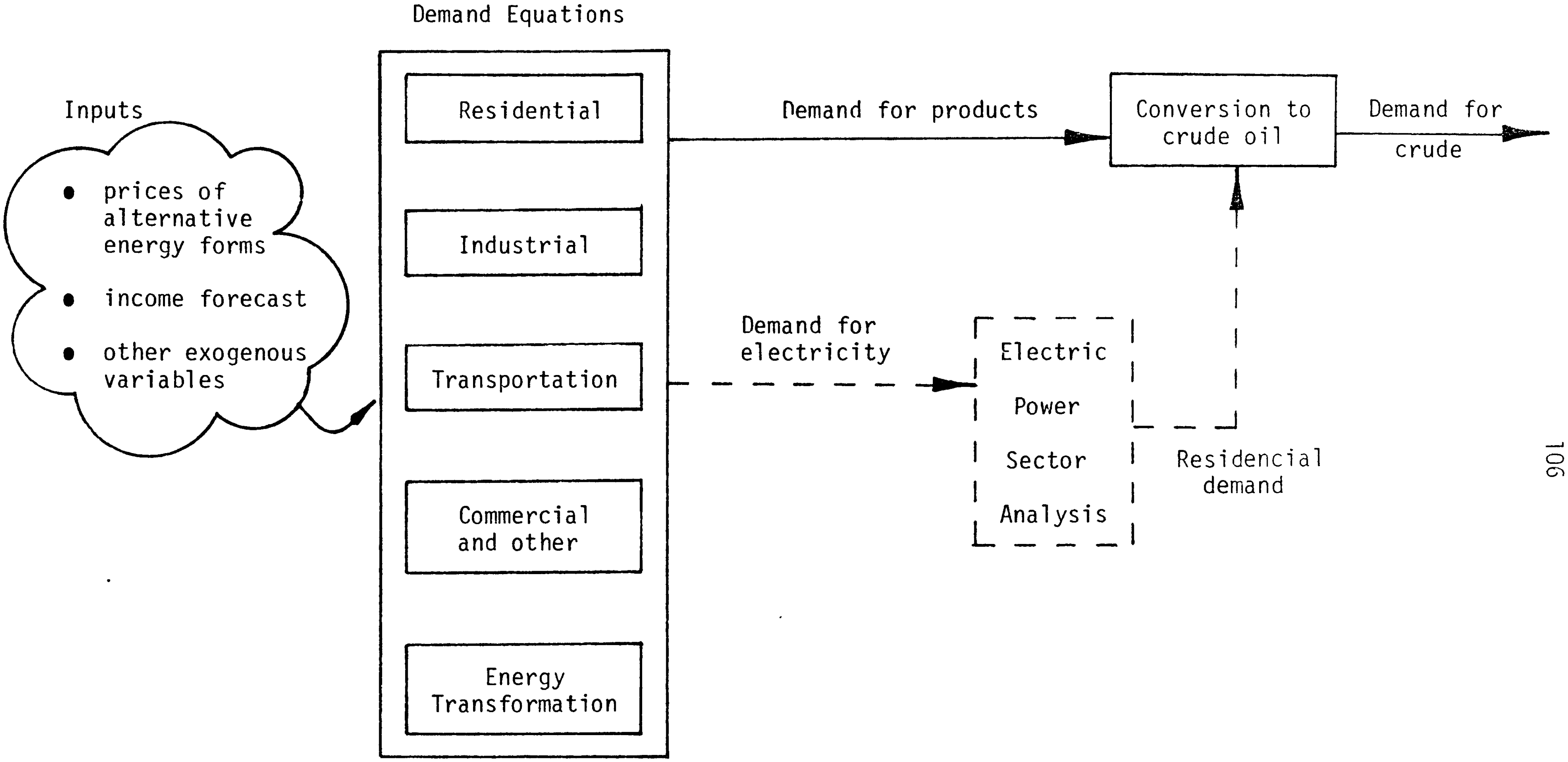


FIGURE 1. OVERALL ANALYSIS FRAMEWORK



Notes: (a) Individual demand equations may be estimated from pooled cross-section data.

(b) The electric power sector analysis shown in the dashed lines has not yet been implemented.

FIGURE 2. DEMAND MODULE FOR AN INDIVIDUAL COUNTRY

REGION SECTOR/FUEL	USA CANADA	JAPAN	BELGIUM	FRANCE, ITALY, NORWAY, SWEDEN, NETHERLANDS, UK, W. GERMANY	OTHER WESTERN EUROPE	BRAZIL, AUSTRALIA, SOUTH AFRICA	OIL EXPORTING COUNTRIES	NON-OIL EXPORTING LDCs
INDUSTRIAL	Translog	Translog	Smoothed log-log with lags	Translog	-	-	-	-
RESIDENTIAL	Translog	Smoothed log-log with lags	Translog	Translog	-	-	-	-
TRANSPORTATION MOTOR GAS DIESEL	Smoothed log-log with lags	Smoothed log-log with lags	Smoothed log-log with lags	Smoothed log-log with lags	Regression on translog Europe	Regression on developed countries	-	-
ALL OTHER	Smoothed log-log with lags	Smoothed log-log with lags	Smoothed log-log with lags	Smoothed log-log with lags	-	-	-	-
EVERYTHING BUT MOTOR GASOLINE	-	-	-	-	Regression on translog Europe	Regression on developed countries	-	-
TOTAL PRODUCTS	-	-	-	-	-	-	Growth at historical rates	Tied to Europe
PRODUCT PRICES	Mark-up mechanism	Mark-up mechanism	Mark-up mechanism	Mark-up mechanism	-	-	-	-
PRODUCT TAXES	Alterna-tive options	Alterna-tive options	Alterna-tive options	Alterna-tive options	-	-	-	-

NOTES: (1) Equations in box estimated with pooled cross-section of time series.
(2) The "translog" method involves estimation of total energy demand and fuel shares.
(3) The "log-log" method involves estimation of oil demand directly.

FIGURE 3. EQUATION STRUCTURE OF MIT WORLD OIL DEMAND MODEL

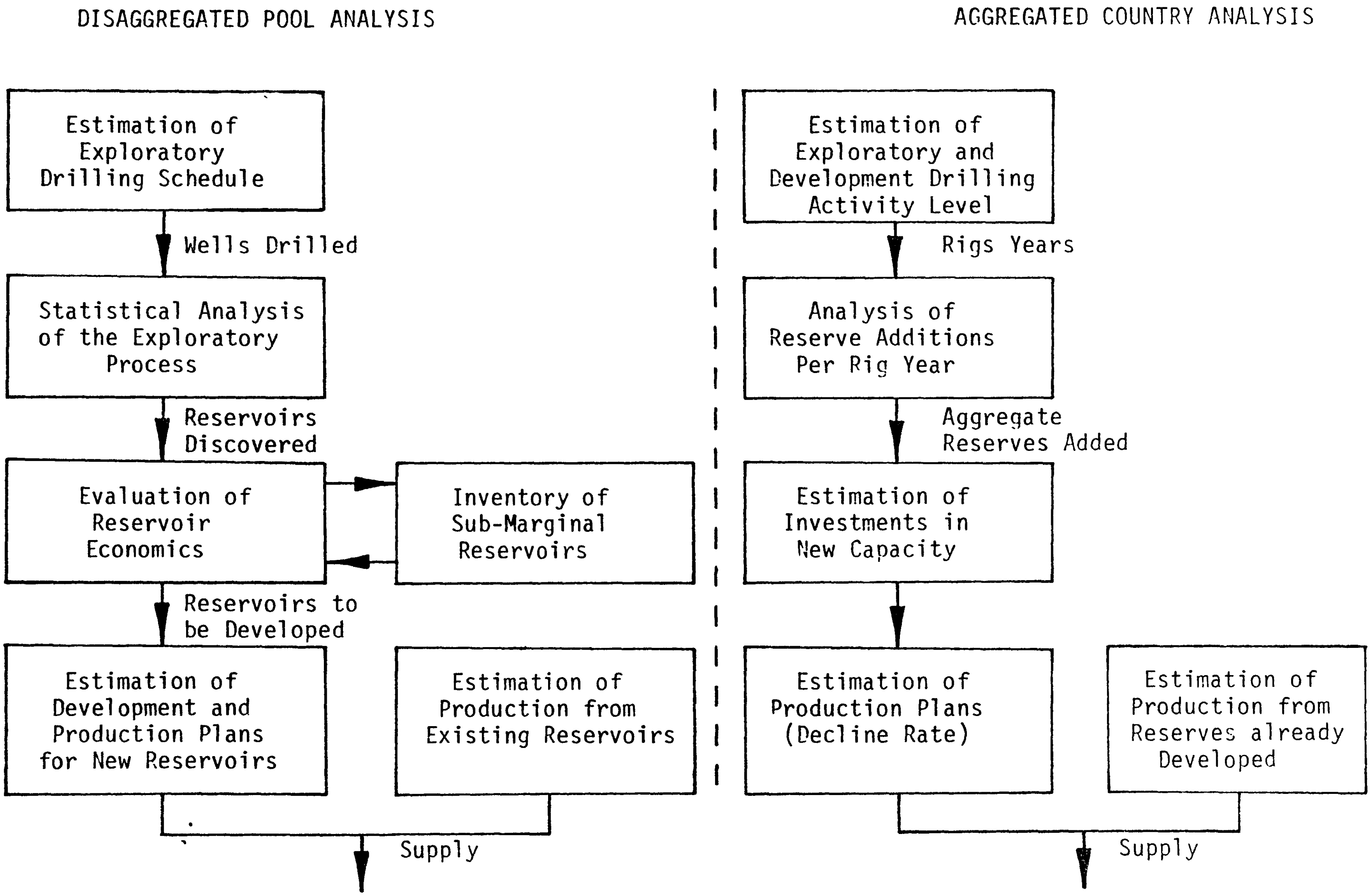


FIGURE 4. OUTLINE OF ALTERNATIVE SUPPLY ANALYSIS METHODS

Table 1

Sample Output of Simulation Run:[a] Selected Series

YEAR	Consumption Forecast: Crude Oil in mbd World (Non-Communist)	Production: OPEC[b]	Non-OPEC[c]	Net Demand on OPEC	OPEC[d] Capacity
1976	49.3	31.9	17.6	31.7	34.6
1977	50.1	30.4	19.8	30.3	34.9
1978	51.2	29.4	22.1	29.1	35.0
1979	51.1	28.5	22.4	28.7	33.3
1980	50.3	27.1	22.8	27.5	33.6
1981	50.3	26.7	23.0	27.3	34.9
1982	50.4	26.5	23.2	27.2	35.1
1983	50.7	26.8	23.3	27.4	35.0
1984	51.1	27.1	23.4	27.7	34.9
1985	51.5	27.6	23.4	28.1	36.3
1986	51.8	27.9	23.4	28.4	36.7
1987	52.3	28.3	23.5	28.8	35.9
1988	52.9	29.0	23.5	29.4	35.7
1989	54.5	30.7	23.8	30.7	35.1

---

a. Assumed Oil Price Scenario

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Price (in 1979 $)[e]	20.66	30.00	29.87	30.14	30.77	31.71	32.66	33.27	33.79	34.16	34.55	35.27

Country	Canada	U.K.	France	W. Germany	Italy	OECE Europe	Japan
GDP Growth Rates							
1977-1985	3.8	2.0	3.6	2.9	2.8	2.7	5.2
1985-1990	3.4	1.7	2.0	1.7	1.9	2.1	3.0

	Australia/N. Zealand	Total OECD	OPEC	Other	World	U.S.
1977-1985	3.3	3.2	6.7[c]	5.1[c]	3.9[c]	3.6
1985-1990	3.5	2.3	6.2	5.2	3.5	3.2

b. Saudi Arabia constrained to 12 mbd maximum

c. Includes Communist Block - Net Exports (mbd)

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1.4	1.5	1.9	1.7	1.5	1.3	1.1	.9	.7	.5	.3	.1	0	0	0

Historical data from British Petroleum, 1980-1990, obtained via linear extrapoation.

d. Assumes development drilling increases at 5% per annum.

e. $ per barrel of oil.

III. DEVELOPING MODELS AND ASSOCIATED DATA COLLECTIONS

1.1 MODEL HISTORY:

a. Name: Electric Generation Expansion Analysis System (EGEAS)

b. Developers: Current development by Dr. Fred C. Schweppe, Richard D. Tabors, Edward J. Moriarty and Michael C. Caramanis of the MIT Energy Laboratory Utility Systems Group; Kenneth Hicks and William Fleck of Stone and Webster; Jeremy A. Bloom from Cornell University. In the past other MIT Energy Laboratory and Stone and Webster affiliated researchers have been involved in the development of options currently incorporated in EGEAS.

c. Duration: Full package under development [scheduled to be completed by the end of 1981]. Some modules already available and documented.

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsors: Electric Power Research Institute; Department of Energy

1.2 MODEL DESCRIPTION

a. Summary

EGEAS is being developed as a state-of-the-art model for electric utilities expansion planning. The software design will be flexible and modular, so a common data base and control program can be used for a set of core analyses as well as for running optional advanced feature packages. Three different optimization methods will be incorporated within the EGEAS model: linear programming, dynamic programming, and generalized Benders decomposition. In addition, two other analysis options will also be provided: static year-end optimization and analysis of user-pre-specified expansion pathways. The model will be able to handle solar and other time-dependent generation, storage, environmental impacts, load modification, interconnections, and sensitivity analysis. It will incorporate a modified version of SYSGEN, a software package that uses Booth Baleraux simulation, to calculate production costs and system reliability.

Figure 1 (see page 114) is a system overview representation of EGEAS. The objective of the LP module, which is based on the GEM model developed at MIT, is to find the least cost, environmentally acceptable expansion schedule subject to demand and reliability constraints, fuel availability, and other resource constraints. A set of expansion alternatives are screened based on results of dispersion modeling. The LP then selects an expansion schedule given the environmentally acceptable expansion alternatives and their assumed capacity factors subject to constraints on peak load, energy fuel availability, site air and thermal emissions, and total system and thermal emissions. A production costing model then determines actual capacity factors given the expansion schedule and feeds this information back to the LP . The iterations continue until an optimal solution is reached. (See Figure 2, page 115.)

OPTGEN, a dynamic programming model developed by Stone and Webster Engineering Corporation, will be modified and developed further to form the DP capability of EGEAS. The DP module will generate optimal and near-optimal expansion plans with discrete plant sizes. It will use forward and backward dynamic programming to minimize the present worth of total capital and operating costs. Three options will be available for calculating operating costs: the loading triangle method, probabilistic loading using deconvolution, and expected fuel costs calculations.

The decomposition technique uses an LP to select an expansion schedule and then uses the production costing/reliability module to compute shadow prices for each selected expansion alternative relative to operating costs and relative to meeting the system's reliability constraints. These shadow prices are then fed back to the LP and the process is repeated. This method is now being developed to handle new technologies, load modifications, storage units, cogeneration, and limited energy plants as decision variables.

b. Data Base

Figure 3 (see page 116) gives a general representation of the proposed EGEAS data base. A single data base is created from which any of the expansion optimization modules or production cost/reliability analysis can be run. Figure 4 (see page 117) depicts the input parameters required for the LP analysis.

The DP module requires the following input parameters: inflation rates, fixed charge rates, interest rates, existing generating unit data, heat rates, outage rates, load data, data for alternative types of units, capital and operating costs, and reserve and reliability constraints.

The central data base of EGEAS will be designed to facilitate easy interfacing with the external data bases required for running optional advanced features such as financial analysis, transmission and distribution, etc.

c. Computer Aspects

Structured programming concepts are being applied for designing and coding EGEAS software. The programs, which will all be in FORTRAN, are being developed according to the following guidelines: compatibility on different computer systems, high degree of modularity, and user orientation. Extensive documentation will be provided, covering all aspects of the model.

GEM, OPTGEN, and SYSGEN are already in use at MIT and other places and have been tested on utility data. Further development work on all

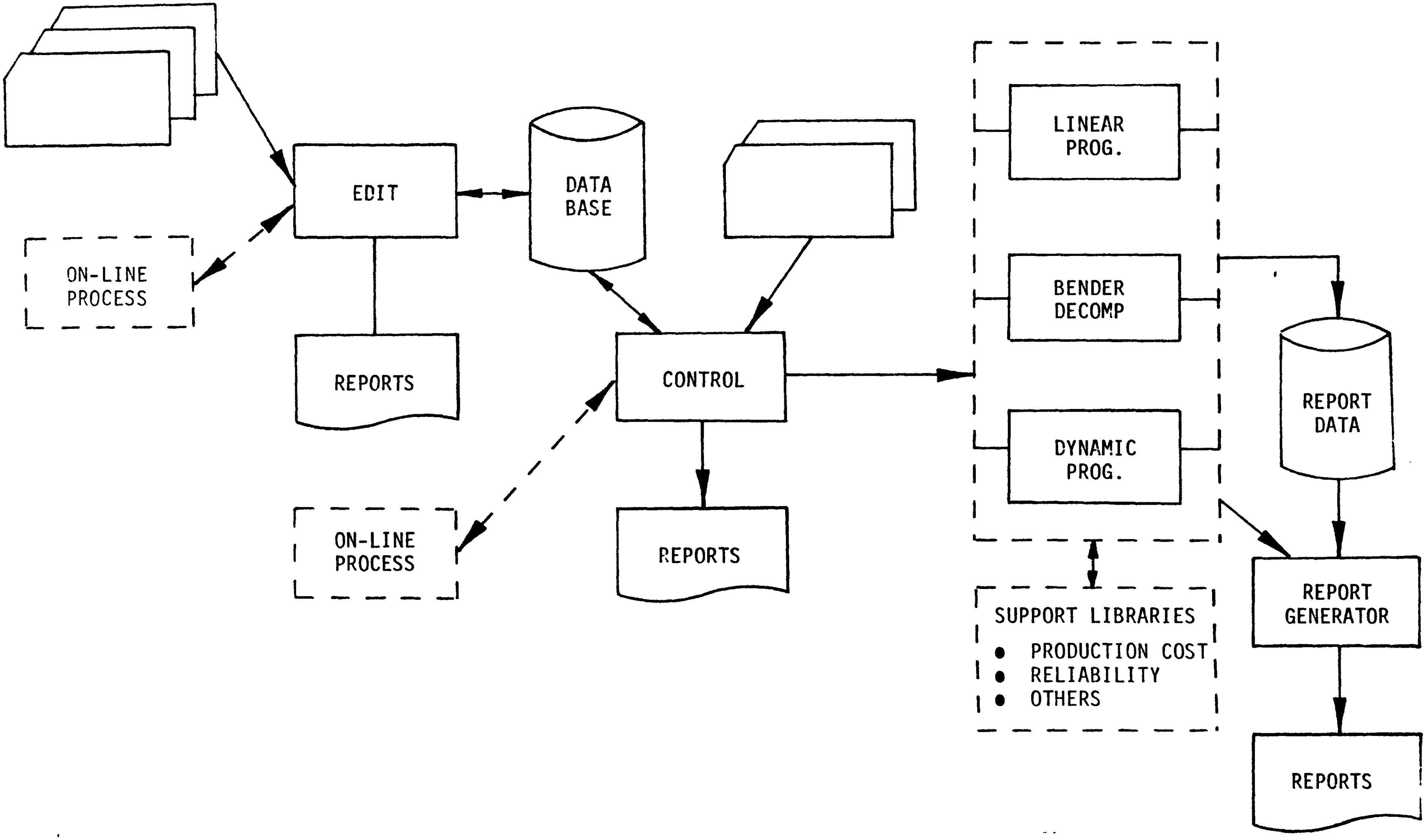


FIGURE 1. EGEAS SYSTEM OVERVIEW

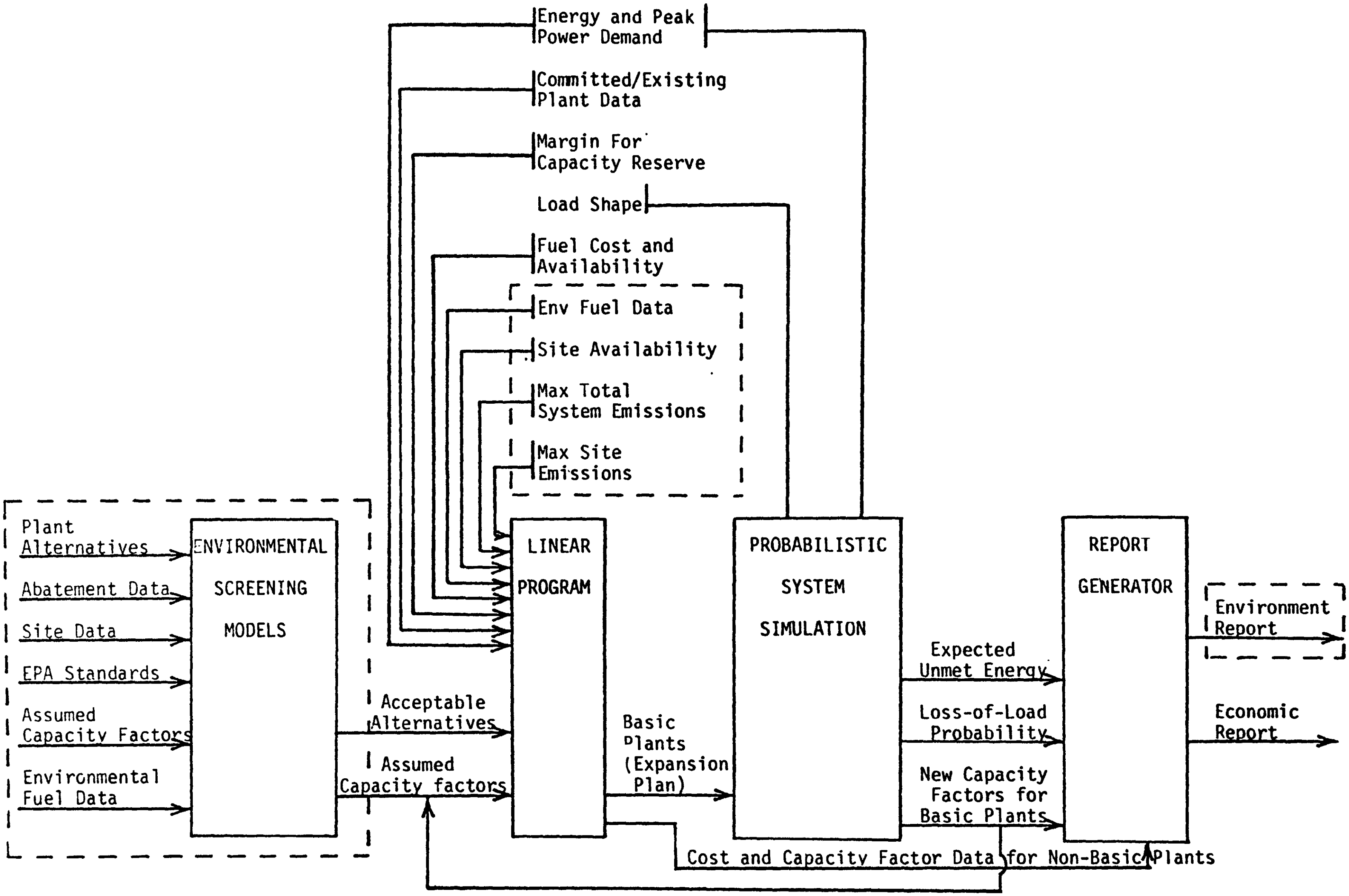


FIGURE 2. DETAILED FUNCTIONAL DIAGRAM OF LP MODULE

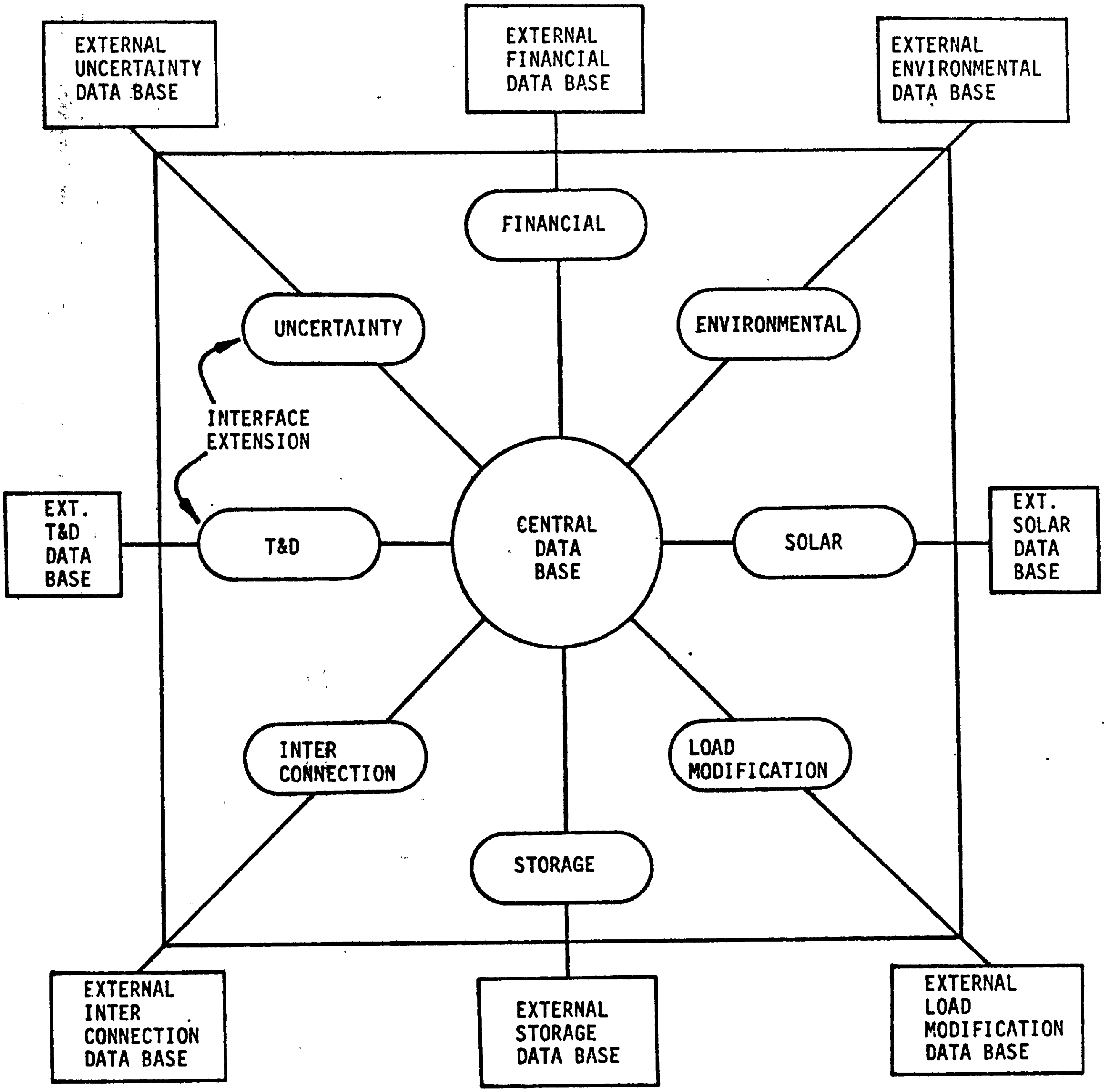


FIGURE 3. GENERAL REPRESENTATION OF PROPOSED EGEAS DATA BASE

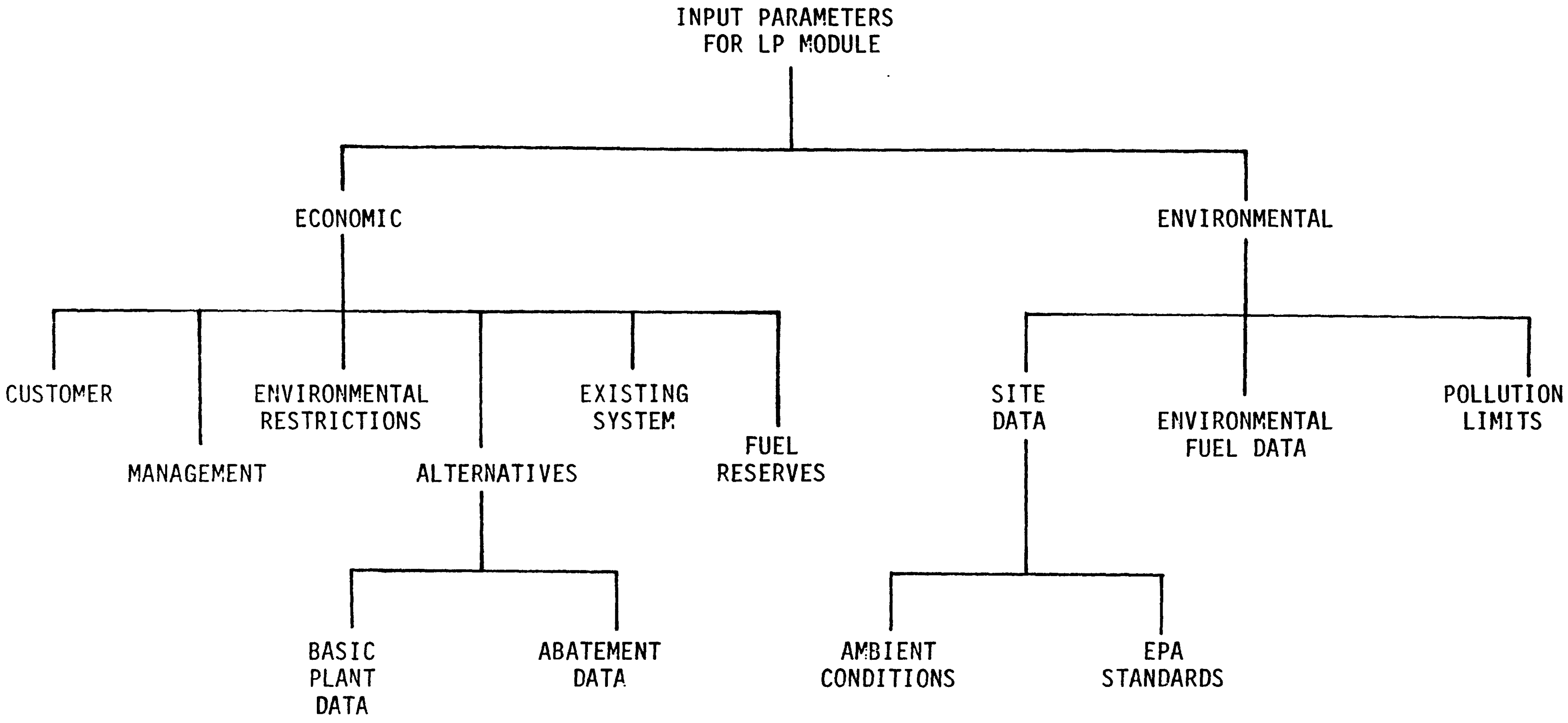


FIGURE 4. INPUT PARAMETERS FOR LP MODULE

2.1 MODEL HISTORY

a. Name: Residential Energy Demand Model

b. Developers: Raymond S. Hartman, Department of Economics, Boston University, and Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts; Alix Werth, Ralph Braid, Daniel Saltzman, Mary Litterman, and William Wallace, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: June 1977 through 1985 (projected)

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsor: Department of Energy

2.2 MODEL DESCRIPTION

a. Summary

The main purpose of the MIT Residential Energy Demand modeling effort is to develop a model that properly identifies the short-run and long-run characteristics of residential energy demand behavior. The resulting model explicitly incorporates both technical characteristics of traditional and new energy technologies and consumer response to them. The model will be used to help the Department of Energy understand and plan for residential acceptance and use of a new technology--solar photovoltaics.

The basic methodological approach involves a combination of econometrics, probability models, and engineering analyses of residential appliances. Econometric models are used to predict short-run energy demand, conditional upon the size and characteristics of the residential appliance stock. For example, letting i represent one of n different end-uses (including space heating, water heating, cooking, air conditioning, clothes washing, clothes drying, regrigeration/freezing, and dishwashing), the short-run model tests electricity demand for household j in time t (q_{jt}) as:

$$q_{jt} = \sum_{i=1}^{n} q_{ijt} = \sum_{i=1}^{n} U_{ijt} (P_{jt}, y_{jt}, w_{jt}, se_{jt}) K_{ijt}$$

where U_{ijt} is the utilization rate of appliance K_{ijt} and U_{ijt} is conditional on P_{jt} (the price of electricity), y_{jt} (household income), w_{jt} (weather and climate effects) and se_{jt} (all other relevant socioeconomic factors).[1] Probability models of consumer choice (logit, probit) are used to measure residential choice among alternative fuels and alternative technologies. These models relate the probability of appliance purchase to the relative desirability of the potential alternatives. For example, the probability that household i will choose appliance/fuel j is functionalized using logit analysis as:

$$P_{ij} = \frac{e^{Z_{ij}\beta}}{\sum_{k=1}^{n} e^{Z_{ik}\beta}} = \frac{1}{\sum_{k=1}^{n} e^{(Z_{ik} - Z_{ij})\beta}}$$

where Z_{ij} is the vector of attributes of alternative j for individual i and β is a vector of weights (preferences) indicating how individual i values attributes of j and k. Notice in the equation that the probability is a function of the relative (binary comparison) desirability of j,

$$e^{(Z_{ik} - Z_{ij})\beta}.^{2}$$

The alternative technologies are characterized by engineering analyses.

The model structure and results remain tentative. The short-run component has been specified and estimated; however, it will be refined over the 1979/1980 academic year. The long-run components are being specified and estimated.

b. Data Base

The Residential Energy Model Project data collection was developed to specify residential consumer behavior, and includes detailed information about residential consumer appliance ownership and usage. The data collection is composed of several subsections originally compiled by different individuals and organizations. Some of the data are pooled, aggregated time series, obtained from public sources; some are disaggregated, household data obtained from household surveys. Each subsection below describes the methodologies and sources employed. The computerized storage will also be described.

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[1] See Hartman, R.S., "A Model of Residential Energy Demand," MIT Energy Laboratory Report, forthcoming, and Hartman, R.S. and Werth, A., "Short-Run Residential Demand for Fuels: A Disaggregated Approach," MIT Energy Laboratory Report, forthcoming.

[2] Hartman, R.S., "A Note on the Use of Aggregate Data in Individual Choice Models," MIT Energy Laboratory Working Paper, forthcoming, and Hartman, R.S., "Discrete Consumer Choice Among Alternative Fuels and New Technologies for Residential Energy Using Appliances," MIT Energy Laboratory Working Paper, forthcoming.

Pooled Times Series of Cross-Sections: Aggregate Data

A major portion of the aggregate data was originally developed by Data Resources, Incorporated (DRI) for the Electric Power Research Institute. These were supplemented with data from the Baughman-Joskow Regionalized Electricity Model. Some improvements of the DRI time series were incorporated, and some additional time series were collected. The data report items such as stock of housing, stock of appliances, temperature data, degree days, and fuel consumption. The data are for all 50 states, with the range of years usually 1960-1974, some from 1955-1978. The original DRI data and the improvements and additions will be described below.

Appliances

Time series were constructed for the period 1959-1974 (updated to 1976) for nine types of appliances: refrigerators, freezers, air conditioners, electric ranges, electric water heaters, automatic washers, conventional washers, electric dryers, and dishwashers. Saturation rates for these appliances were obtained using the rates published in the magazine Merchandising Week, adjusting these figures to match those available in the 1960 and 1970 Bureau of Census figures, and the times series constructed to preserve the trend in the Merchandising Week data. Problems associated with merging these two data sets stemmed from differences in the sample definition, and differences in coverage. Merchandising Week obtains its data from utility companies (but not all utilities are included) while the Census data are from surveys. The stock of these appliances is then computed as the product of the saturation rate and the housing stock (see Housing Stock below).

Another methodology was employed to construct an alternative to the DRI time series for saturation rates and stocks of electric and gas appliances (except for refrigerators and dishwashers). This was done by fitting a special time trend through the diennial Bureau of Census saturation rate. Stocks were then obtained by multiplying by annual housing stocks (see below).

Housing Stock

These series are considered to be an important element in the analysis, since allocations of heating and cooling equipment and appliance stocks are constructed using housing stock time series.

The sources used were the 1960 and 1970 editions of the Census of Housing from the Census Bureau, series C-40, which report new housing permits. The data are broken out into single, multiple, and mobile units. Yearly stocks were then calculated using depreciation rates.

These series were finally judged to be inadequate due to errors in the data. An alternative was developed--the number of electric utility customers. This was chosen as a good estimate for housing stock because of the nearly universal use of electricity in the U.S. The number of customers was then adjusted to match the estimates of housing units in the Census figures. This series was used as the final housing stock data, although it meant sacricifing the breakdown of single, multiple, and mobile home units.

Electricity Charges

Implicit fixed charges and marginal prices for the marginal block are calculated using average expenditure level, average price level, average demand, last block in the rate schedule, and sales at 100kWh to determine the marginal block level in dollars/month. The cost of 1550 kWh/month in dollars was also calculated.

Stock of Houses Heated by Fuel Oil, Natural Gas, and Electricity

The stock of houses heated by natural gas was obtained from the American Gas Association, which publishes estimates each year. The number of electrically heated homes was obtained from the FPC's Typical Electrical Bills for Electrically Heated Homes, which reports, by utility, the number of customers who benefit from special rates available for electric space heating. When these figures were compared to those available from the Bureau of Census for 1960 and 1970, large discrepancies were found. Therefore, the FPC numbers were adjusted by inflating by the ratio of total customers in a state to the total customers reporting. The number of housing units heated by fuel oil was then determined as a residual category. These series, developed by DRI, were supplemented using different depreciation rates to determine the number of newly constructed houses.

Stock of Houses Using Electricity, Gas, or Oil for Water Heating

Analysis of Bureau of Census data indicated a relationship between space heating by fuel type and water heating by fuel type, with some regional differences. The determination of the stock of housing using gas, electric, or oil water heating therefore was based largely on the space heating data.

Housing Stock Shares

Shares of housing stock for single unit, multiple unit, and mobile homes were calculated with the housing stock data series described above, as well as the time series for stock of electric-, gas-, and oil-space heated homes.

Central Air Conditioning

The number of occupied units with central air conditioning was obtained using Census of Housing data for 1960 and 1970. For the remaining years, factory shipments reported by the Air Conditioning and Refrigeration Institute, which distinguishes residential and commercial shipments, were used. Stocks of central air conditioners as a function of shipments were calculated to allocate units to states.

Development of Alternative Time Series

Electric Appliance Gross Investment

Annual electric appliance gross investment and coverage rates were calculated. The coverage rate was defined as the ratio of reported sales of an appliance to the number of customers served by all utilities in the state. These time series are available in the DRI data collection, where they were originally obtained from *Merchandising Week*. Appliance gross investment was then calculated as the ratio of the state sales of the appliance to the coverage rate.

Gas Appliance and Alternative Electric Dryers Gross Investment

Yearly state shipments of the appliances were obtained from the Gas Appliances Manufacturers Association and the Association of Home Appliance Manufacturers. These were then divided by yearly national shipments, as reported in *Merchandising Week*, to obtain a coverage rate. Gross investment was then obtained by dividing the states' shipments by the coverage rate.

Prices, Temperature, CPI, Area, and Consumption Time Series from the Baughman-Joskow REM Data Collection

Certain cross-sectional time series for the 50 states, developed for the Baughman-Joskow Region Electricity Model, were incorporated. Some of these time series range from 1955-1978, most from 1970-1974. All are from published sources. These series include the land area of each of the 50 states, average monthly minimum and average monthly maximum temperatures, a consumer price index for all commodities, and residential prices and consumption of natural gas, number 2 fuel oil, and electricity. See the description of the Baughman-Joskow data collection for information on sources.

Times Series Developed for Short-Run Demand Analysis

Revenues and Sales of Fuel

Revenue from sales of natural gas in $1000 and sales of natural gas in million cubic feet were obtained from *Gas Facts*, published by the American Gas Association. Sales of number 2 fuel oil and total distillate oil sales in thousand barrels were obtained from the American Petroleum Institute.

Electricity

Sales of electricity in millions of kilowatt hours were obtained from the Edison Electric Institute's *Statistical Yearbook*.

Miscellaneous

Heating and cooling degree days were obtained from the National Oceanic and Atmospheric Administration. Personal income in current and constant dollars was obtained from the Survey of Current Business. The number of households was also obtained from the Survey of Current Business.

Residential Appliance Characteristics Data

Times series of the average efficiencies of six major residential appliances were created. The range of years is 1959 to 1976 and the appliance classes are: space heaters, refrigerators/freezers, clothes dryers, air conditioners, water heaters, and kitchen ranges. Time series for installed cost estimates, by state, for selected residential heating systems were also developed. The range of years is 1959-1976. The sources and methodology used to construct these time series is described below.

Appliance Efficiencies

Standards developed by the National Bureau of Standards and the FEA were used to determine appliance efficiencies. The definition of efficiency, BTU output/BTU input, was not used due to data unavailability.

Efficiency rates from American National Standards Institute (ANSI) were obtained from publications of Consumer Research, Incorporated and from the laboratories of the AGA, where appliances are tested and scored on performance criteria. The Association of Home Appliance Manufacturers also provides data on efficiences.

Different sources were used for oil-fired furnaces. The ANSI standard is available from the National Fuel Oil Institute, and the actual performance evaluation was obtained from individuals at Brookhaven National Laboratories, where a project directly monitors and records the performance of oil-fired furnaces.

A weighted average was developed using annual sales of each appliance. The sales data used for weighting the average were obtained from reports in the magazine Merchandising and the Bureau of Census' annual Current Industrial Reports.

Installed Cost of Space Heating Systems

A time series was constructed for each of the 50 states using annual editions of "Building Construction Cost Data" published by R.S. Means, Company. The published series has two components--material cost and labor cost--and gives total cost. An index for 50 cities developed by the publisher, starting in 1965, was used.

Dissagregate Household Data

Survey data developed for EPRI by the Midwest Research Institute has been incorporated in the Residential Energy Demand Project data collection. The original purpose of the survey was to estimate the population parameters associated with electrical appliance usage. 1,985 households, located in 16 U.S. cities, were included. The cities chosen are a random selection of cities where the electric utility company was willing to cooperate. The subject population was stratified twice, by region and by city size, to minimize the variance. The survey methodology and information collected, during the period August 1976 to July 1977, is described below.

Primary Household Survey Data

Personal interviews were conducted at each of the households in the survey. The data collected included:

a) type of residential area

b) type of residence

c) number of occupants

d) the relationship of the occupants

e) the age of the head of the household

f) gross family income

g) employment status

h) method of space heating

i) availability of natural gas

j) physical characteristics of the house

k) type of major electrical appliances

l) type of minor electrical appliances

Home Heating Survey

Telephone interviews with each of the original 1,985 households were conducted to obtain the following information:

a) major heating system in house

b) major fuel used to heat house

c) additional heating systems used

d) location and quantity of recently added insulation

e) fuel type used for hot water heating

f) fuel type used for cooking

g) type of fuel used by clothes dryer

Household Energy Usage Data

Three methods were used to obtain household energy usage data. Electrical bills for a one-year period for each of the surveyed households were obtained from the local utilites. The data collected from the bills include:

a) quantity of electricity used

b) rate schedule, type of reading, reading dates

c) energy cost, taxes (total cost)

Another method of obtaining household energy usage data involved a subset of the primary survey homes. Meters were placed on major electrical appliances of 150 homes. These meters were then read once a month. The major appliances metered were:

a) refrigerators

b) freezers

c) electric ranges

d) electric hot-water heaters

e) room air conditioners

f) central air conditioners

g) clothes washers

h) electric clothes dryers

i) dishwashers

j) swimming pool pumps

k) electric furnaces

The third method used to obtain household energy usage data used gas bills from some of the surveyed households. Gas bills from approximately 700 homes were used to obtain:

a) quantity of gas used

b) price of gas to household

Qualifications

Some limitations of the Survey data stem from: 1) rural residences are not represented, and 2) apartment dwellings were under-sampled.

c. Computer Aspects

The model has not been computerized yet. When it is it will be done along the lines of the Oak Ridge residential model.[3]

All data described above are currently stored on-line, on either the MIT IBM 370 TROLL system, or the MIT Honeywell, MULTICS System. The aggregate data are on TROLL, a user's guide provides a key to data file names, and working papers document the data. The disaggregate data are stored on the MIT MULTICS, data-base management system. Documentation of this data is not yet available.

2.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The planned applications of the full-scale model will begin in 1981-1982. At that time the model will be used to help the Department of Energy plan for commercialization of photovoltaic installations within the residential sector.

2.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the modeling project)

Braid, R., "The Development and Critical Review of Annual Stock and Gross Investment Data for Residential Energy-Using Capital," MIT Energy Laboratory Technical Report No. MIT-EL 78-046TR, June 1978.

The basis for much aggregate energy demand data is an effort by Data Resources Inc. for the Electric Power Research Institute. Those data have problems; several of them are discussed in this document. Alternative series are developed.

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[3] Hartman, R.S., "Discrete Consumer Choice Among Alternative Fuels and New Technologies for Residential Energy Using Appliances," MIT Energy Laboratory Working Paper, forthcoming.

Data Resources, Inc., "The Residential Demand for Energy: Estimates of Residential Stocks of Energy Using Capital," report to the Electric Power Research Institute, EPRI ea-235, January 1977.

This is the original Data Resources Inc. effort to develop pooled time-series cross-sectional data for residential appliances, residential energy demand and energy prices. It has since been revised (September 1979).

Energy Management and Economics Group, "The Conditional/Generalized Maximum Likelihood Logit Computer Program: Instructions for Use," MIT Energy Laboratory Report No. MIT-EL 78-013, June 1978.

This paper documents a computer program that can be used to do logit analysis. The program was originally developed by Charles Marski and has been updated by others.

Hartman, R.S., "Frontiers in Energy Demand Modeling," <u>Annual Review of Energy</u>, Vol. 4, 1979.

This paper provides a critical survey of residential, commercial and industrial energy demand models and develops a paradigm model for such models.

Hartman, R.S., "A Critical Review of Single Fuel and Interfuel Substitution Residential Energy Demand Models," MIT Energy Laboratory Report No. MIT-EL 78-003, March 1978.

This paper critically reviews a wide array of residential energy demand models that focuses upon single fuels or upon the demand for alternative fuels.

Hartman, R.S., "A Model of Residential Energy Demand," MIT Energy Laboratory Report, forthcoming.

This paper provides an overview of the full residential energy modeling effort under way at the MIT Energy Laboratory. That effort includes a long-run analysis and a short-run analysis.

Hartman, R.S. and Werth, A., "Short-Run Residential Demand for Fuels: A Disaggregated Approach," MIT Energy Laboratory Report, forthcoming.

This paper presents results for the short-run component of the model described.

Hartman, R.S., "A Generalized Logit Formulation of Individual Choice," MIT Energy Laboratory Working Paper No. MIT-EL 79-010WP, February 1979.

This paper examines and estimates a model of individual choice more general than a conditional logit model. This more general model, the generalized logit model, avoids some of the problems of the conditional logit model, in particular the independence of irrelevant alternatives.

Hartman, R.S., "A Note on the Use of Aggregate Data in Individual Choice Models," MIT Energy Laboratory Working Paper, forthcoming.

This paper examines the effects of using aggregate data in estimating the parameters of an individual choice model.

Hartman, R. S., "Discrete Consumer Choice Among Alternative Fuels and New Technologies for Residential Energy Using Appliances," MIT Energy Laboratory Working Paper, forthcoming.

This paper develops the formal analysis for modeling consumer choice among alternative fuels and a wide array of technologies for residential energy-using appliances. The analysis forms the basis for the long-run component of the residential model.

McCormick, S.T., "User's Guide to the Oak Ridge National Laboratory Residential Energy Demand Model," MIT Energy Laboratory Working Paper, forthcoming.

Oak Ridge has developed a model of residential energy demand available at MIT. This paper describes how to use it.

Midwest Research Institute, "Patterns of Energy Use by Electrical Appliances," report to the Electric Power Research Institute, EPRI ea-682, January 1979.

This is the source of disaggregated household data for residential energy demand analysis.

MIT Residential Energy Demand Group, "Aggregate Pooled Data Utilized and/or Developed for Residential Energy Demand Analysis," MIT Energy Laboratory Working Paper, forthcoming.

This paper summarizes all aggregate data (pooled annual time-series of state cross-sections) developed or gathered in the effort to estimate a proper residential energy demand model.

Saltzman, D., "The Development of Capital Cost and Efficiency Data for Residential Energy-Using Equipment," MIT Energy Laboratory Working Paper No. MIT-EL 79-059WP, October 1979.

This paper describes one component of the data-gathering effort.

Werth, A., "Residential Demand for Electricity and Gas in the Short Run: An Econometric Analysis," MIT Energy Laboratory Working Paper No. MIT-EL 78-031WP, June 1978.

This paper presents estimation results for the short-run component of the residential energy demand model.

3.1 MODEL HISTORY

a. Model:	Optional Energy Systems Simulator (OESYS)
b. Developers:	Richard D. Tabors, Alan C. Cox, and Tom L. Dinwoodie, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c. Duration:	No termination date
d. Location:	MIT Energy Laboratory Utility Systems Program/ Photovoltaics Project, Cambridge, Massachusetts
e. Sponsor:	OESYS is part of a larger project funded by the Department of Energy to study the commercialization of Solar Photovoltaics

3.2 MODEL DESCRIPTION

a. Summary

This computer model is non-optimizing (not an LP) but is rather an evaluative mechanism with broad capabilities for energy transfer accounting between pre-defined generation and load profiles. It is employed by first explicitly defining the service environment. This is done by mapping all load and generation nodes, including storage points, for each specific level of energy quality being considered. Energy quality at each node is explicitly defined as either electricity, a specific grade of thermal energy, a gaseous or liquid fuel, etc. The model skeleton is that of a grand accounting routine that keeps track of the pre-matched energy supply and demand modes and assigns an economic value to all energy transfers.

Generation and load profiles are supplied by the user in the form of hourly or sub-hourly energy figures, while characteristics of the operating environment are input in the form of parameter values. The program will interface with user-supplied applications or process models that generate energy consumption/production in actual simulation time. The structure of this model is depicted in Figure 1 (page 134).

The model's capabilities include:

1) utility interface and stand-alone operation; the utility environment allows both conventional- and application- (demand) dependent rate setting strategies;

2) matching of energy supply technologies with like demand across the energy quality spectrum;

3) specification of energy supply strategies to include:

   a. cogeneration

   b. forced generation (weather-dependent technologies)

   c. backup (utility, diesel, TOTEM, etc.)

4) specification of the energy environment by user-load profiles;

5) application of demand elasticities to individual users within the modeled site; treatment of demand elasticities is flexible and much to the discretion of the modeler;

6) handling of dedicated or system storage;

7) economic accounting subject to specified market and financial parameters;

8) a dynamic project appraisal capability for evaluating the profitability of various construction delay strategies; and

9) output summaries as follows:

   a. run characteristics

   b. economic accounting

   c. reliability indices

   d. graphic plots of both operating and economic/cost characteristics

   e. demand-not-placed (on utility) tapes over any year within the run life of the system (for analysis in effecting load duration curves for utility capacity expansion models).

b. Data Base

Several data collections support the model, including SOLOPS and SOLMET. These two data collections are described separately in Section IV of this directory.

c. Computer Aspects

OESYS was written on the MIT IBM VM/370, in CMS, FORTRAN IV. Development started in 1979. The model is dependent on solar and application load profiles.

3.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

OESYS is currently being used by the MIT Utility Systems Program/ Photovoltaics Project to evaluate the economic worth of photovoltaics in utility interface operating modes. It will soon be used to investigate the market environment for Photovoltaic/Thermal residential applications in conjunction with the MIT Lincoln Laboratory. Studies are also planned with the MIT Mechanical Engineering Department, which will use OESYS to investigate a cogeneration unit. Other developments to be completed in the next year include equipping the model to handle utility interface/dispersed electrical/thermal generation, dedicated thermal storage, utility interface/residential-scale cogeneration, and dedicated thermal storage.

3.4 WORKING PAPERS AND ARTICLES (generated by the OESYS Project)

Cox, A.J., "The Economics of Photovoltaics in the Commercial, Institutional, and Industrial Sectors," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January, 1980.

This paper describes the application of a model that computes system break-even capital costs, array break-even capital costs, and profits from photovoltaic investments in the industrial, commercial, and institutional sectors. Several tax and accounting combinations are described and utilized in this paper. Results indicate that, at rates of return usually found in the industrial and commercial sectors, photovoltaic investments will not be attractive when the costs of those investments are based on the Department of Energy's cost goals for 1986.

Millner, A.R. and Dinwoodie, T.L., "System Design, Test Results, and Economic Analysis of a Flywheel Storage and Conversion System for Photovoltaic Applications," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January 1980.

MIT Lincoln Laboratory is developing a flywheel interface and storage system for use with photovoltaic power sources. Test data on the performance of components built to investigate the feasibility of such a system, and the results of economic studies of the system showing user-worth analysis and manufacturing-cost estimates, are presented. The system has magnetic bearings, a maximum-power-point tracker, DC input, and cycloconverter output from an ironless-armature motor-generator.

Dinwoodie, T.L., "Flywheel Storage for Photovoltaics: An Economic Evaluation of Two Applications," MIT Technical Report No. MIT-EL 80-002, February 1980.

A worth analysis is made for an advanced flywheel storage concept for tandem operation with photovoltaics currently being developed at MIT/Lincoln Laboratories. The applications examined here are a single-family residence and a multi-family load center, 8 kWp and 100 kWp, respectively. The objectives were to determine optimal flywheel sizing for the various operating environments and to determine the financial parameters that would affect market penetration. The operating modes included both utility interface and remote, stand-alone logics. All studies were performed by computer simulation.

The analysis concludes that flywheel systems are more attractive in residential applications, primarily because of differences in financing parameters and, in particular, the discount rate. In all applications flywheel storage is seen to increase the optimal size of a photovoltaic system. For stand-alone environments, optimum configuration sizing is fairly insensitive to hardware cost of photovoltaics and flywheels for a given reliability when no diesel generator is included.

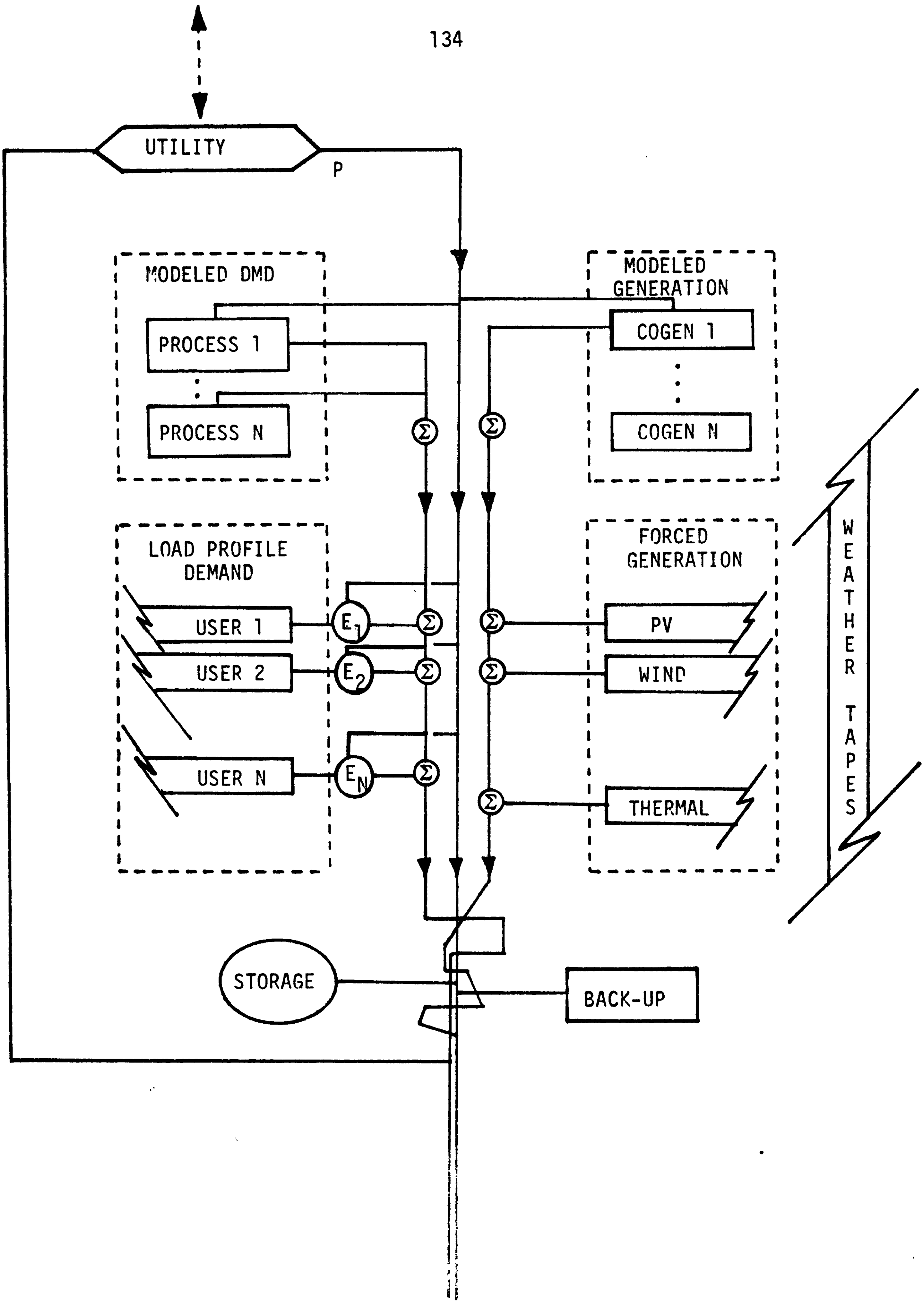

FIGURE 1. MODEL STRUCTURE

4.1 MODEL HISTORY

a. Name:	Probabilistic Oil Discovery Models
b. Developers:	James L. Smith, University of Illinois and Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts Geoffrey Ward, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts Frank M. O'Carroll, British Petroleum Company, Limited
c. Duration:	September 1979-August 1980.
d. Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e. Sponsors:	Center for Energy Policy Research; Norwegian Research Council for Science and Humanities, Center for Applied Research of Norwegian School of Economics; and Center for Petroeconomic Studies of the Christian Michelsen Institute, Bergen, Norway.

4.2 MODEL DESCRIPTION

a. Summary

The model consists of a set of computer programs designed to estimate and simulate a probabilistic model of the oil discovery process, based on the initial sequence of discoveries observed in a known petroleum play. The choice of programs depends on the specific form of the likelihood function and the grid search procedure one desires to use in the search for the likelihood maximizing parameter values. The background and statistical assumptions leading to the likelihood functions are given in James L. Smith, "A Probabilistic Model of Oil Discovery," *Review of Economics and Statistics*, forthcoming, and F.M. O'Carroll and J.L. Smith, "Probabilistic Methods for Estimating Undiscovered Petroleum Reserves," *Advances in the Economics of Energy and Resources*, forthcoming 1980. The goal is to estimate the deposition of oil or oil/gas reservoirs that generated an historical discovery sequence. It is assumed that any reservoir is of one of seven sizes $s_1, \ldots, s_7$, and that originally there were respectively $N_1, \ldots, N_7$ reservoirs in the size classes. The N_i are to be estimated. A refinement is to assume that the deposition was a sample drawn from a "superpopulation" of reservoir with size distributed according to a known distribution function. In either case the parameter estimates are conditioned on the specifying of a value of a "proportionality" constant , as described in the O'Carrol and Smith reference above.

Thus in the case with no superpopulation assumption we wish to maximize the likelihood of the discovery sequence as a function of N_1, ..., N_7, conditonal on a value of . Several grid search methods are available. One is to specify upper and lower bounds for each of N_1, ..., N_7; the program will then evaluate the likelihood (LH) value at each point (X_1, ..., X_7) such that each X_i is an integer and does not lie outside the bounds set for N_i. The program will print out the values of the N_i that lie within the bounds and maximize the LH function; the procedure is now repeated until the globally maximizing N_i are found, as indicated by values that lie in the interior, as opposed to the boundary, of the set defined by the latest bounds. Another grid search method is to set "past" values of N_2, ..., N_7 and a reserve level R; the program will evaluate each point (X_1, ..., X_7) such that X_2 "past" value of N_2, ..., X_7 "past" value of N_7, [class 1 is the residual class], and $X_i S_i$ = R, and print out the LM maximizing N_i. Repeat the procedure until a value of R that results in the highest LM has been chosen. Obviously in either case judicious choice of the search parameters will save computer and human time. Note that the second search method can be used to evaluate the effect of a total reserves constraint and thus obtain confidence limits on total reserves contained in the deposition.

With an assumption on the superpopulation, the search procedures available are the same except that, once is set, one specifies the distribution function parameters before maximizing the LH function on the N_i as above. One then tries alternative values of the distribution function parameters and remaximizes over the N_i until the likelihood function value cannot be improved.

Whether a Weibull or lognormal superpopulation or no superpopulation was imposed the maximum likelihood depositions estimated were almost identical, containing remaining reserves of 9.5 billion barrels, when was set equal to 1. When no superpopulation is assumed, values of near zero, and almost no additional reserves remaining, give highest likelihood values result.

b. Data Base

Depositions have been estimated for the North Sea, utilizing data from a Rand Corporation study and other public sources such as Wood MacKenzie, Robinson and Morgan, North Sea Oil in the Future, and John S. Herold, Inc.'s monthly newsletter.

c. Computer Aspects

The computer programs for the above search procedures/likelihood function specifications are written in FORTRAN and implemented on the CMS system. Initially the user supplies the class sizes S_1, ..., S_7 and the historical sequence of size class indices. If a superpopulation imposition is used, one must also supply a FORTRAN function subroutine to evaluate the distribution function at given size and parameter inputs value.

4.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENTS

Applications have involved estimating North Sea reservoir depositions under no reservoir superpopulation assumption with various values of and with Weibul and lognormal superpopulations imposed with equal to one. Future plans are to examine other values of when a superpopulation is imposed.

4.3 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the modeling project)

O'Carroll, F.M. and Smith, J.L., "Probabilistic Methods for Estimating Undiscovered Petroleum Reserves," in Advances in the Economics of Energy and Resources, forthcoming 1980.

The problem studied in this paper is how to estimate and, if possible, set limits to petroleum resources yet to be discovered in a partly explored area. The approach pursued uses data of the kind normally available in the public domain--historical sequences of fields discovered and estimates of their recoverable reserves, and number of exploration wells drilled. No use is made of geological data or judgment. Four conceptual models are constructed for detailed study, representing a range of levels of sophistication. The performance of these models is examined using data for the Northern North Sea and alternative modeling strategies are compared. The main result is that better results may be obtained with relatively simple models. More ambitious models attempt to improve precision by representing the underlying processes in greater detail. If, however, this representation is incorrect, the net result is to degrade rather than to improve the quality of the results obtained. Hence, until the different aspects of the discovery process are better understood, there is little advantage in using any but the simplest models in the analysis of historical discovery data.

Smith, J.L., "A Probabilistic Model of Oil Discovery," in Review of Economics and Statistics, forthcoming.

This paper presents a discovery model that has been adapted from that of Kaufman with the purpose of simplifying its empirical application. Kaufman and his associates have developed a new method of discovery modeling that provides a simple and appealing structural description of the process of resource discovery and depletion.

The present formulation of the discovery model retains Kaufman's discovery postulates, but re-parameterizes the target population in a manner that facilitates empirical application. The resulting model is applied to the North Sea petroleum provinces, and estimates of remaining reserves and future discoveries are obtained and compared to other estimates taken from the trade press. The method of analysis presented appears to be an important and useful addition to the set of tools available for economic studies of petroleum supply.

5.1 MODEL HISTORY

a. Name: A Macro-Economic Model of Venezuela

b. Developers: Mansoor Dailami, Donough MacDonald, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: January 1979 - September 1979

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsors: National Science Foundation; MIT Center for Energy Policy Research

5.2 MODEL DESCRIPTION

a. Summary

The objective of the model is to analyze how short-term financial considerations influence the oil production policies of oil-exporting countries. The case for Venezuela has been studied. A macro-financial model has been constructed for the economy of Venezuela to analyze the effect of changes in oil revenues on GDP, money supply, government deficit, and government foreign debt. The model has two objectives: a) to analyze the effect of changes in oil exports on the domestic economy of Venezuela; and b) to derive some likely oil export requirements for this country--given the world oil price and the government's overall objectives with regard to growth and monetary stability. The model is essentially a Keynesian-type macro-model that has been modified to capture some of the important characteristics of an oil-exporting country. The model is designed to be particularly suitable for simulation purposes.

It has been found that increases in the oil revenues will have a positive effect on all of the above variables. For instance, an incremental increase of 5 percent in oil revenues from 12.5 to 17.5 percent per year will raise the average annual rate of growth of GDP from 10 percent to 13 percent during the simulation period, i.e., 1978-1985. The model was then used to forecast likely oil exports of Venezuela. Different oil price and economic growth scenarios were used in forecasting oil exports. In view of the recent OPEC oil price adjustments, the author decided to rely on the outcome of the high-oil-price-increase scenario as the most accurate prediction of the actual price of oil in 1980 and 1981. In this case, the oil exports of Venezuela were forecast to be between 1.56 and 1.91 million barrels per day in 1980 and between 1.49 and 1.93 million barrels per day in 1981, if the economy were to grow at a rate between 10 and 15 percent per year during the interim period.

b. Data Base

The data collection that supports the Macro-Economic Model of Venezuela consists of time series on financial activities of the government, and some non-government activity indicators. The range of years is generally 1965-1977 or 1978. The sources used were the International Monetary Fund's Government Statistics, publications of the Central Bank of Venezuela, and national statistical yearbooks.

The data series for the government sector report items of the budget: revenues, expenditures, debt, interest payments, and transfer payments. Non-government data series consist of macro-economic activity indicators such as gross domestic product, national income, and price indices.

Complete documentation of the data series is forthcoming.

c. Computer Aspects

The model was written in TROLL, on the MIT IBM VM/370. Both the model and the data are currently stored on-line. User's guides to the data and the model are forthcoming.

5.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

The author plans to expand the model to encompass detailed activities of the oil sector more explicitly. This will entail explicit representation of investment and consumption expenditures in the development and production stages of oil and gas development.

5.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the MODELING Project)

Dailami, M., "Financial Influences on the Behavior of Oil Exporters," MIT Energy Laboratory Working Paper No. MIT-EL 79-035WP, August 1975.

This paper discusses the influence of financial considerations on the oil production policies of oil producing countries and studies the case of Venezuela and Saudi Arabia.

6.1 MODEL HISTORY

a. Name:	Solar Energy Flux Computation
b. Developers:	Gilberto Russo, Massachusetts Institute of Technology, Energy Laboratory;

Jon McCombie, student at the Department of Electrical Engineering and Computer Sciences, Massachusetts Institute of Technology;

Foroz Mistry, student at the Department of Chemical Engineering, Massachusetts Institute of Technology.

c. Duration: 1978-1980

d. Location: M.I.T. Energy Laboratory, Cambridge, MA

e. Sponsors: Department of Energy

6.2 MODEL DESCRIPTION

a. Summary

An analytical model of the atmosphere has been constructed, based upon the physical interactions of electromagnetic radiation and the constituents of the atmosphere, and it enables the computation of solar energy fluxes on any surface, using generally available meteorological data.

This information is required in studies of engineering optimization and economic analysis of solar energy conversion systems. Experimental values of energy fluxes on the ground are often unavailable and unreliable.

The computation of irradiation (solar energy fluxes) data may also be performed through a stochastic approach, rather than the deterministic criteria used in this model. The stochastic approach (e.g., Monte Carlo techniques) may be performed, or regression techniques may be used, through largely macroclimatic correlations using empirical algorithms, or through large-scale meteo-atmospheric models.

Nevertheless, the deterministic approach (e.g., the analytical model of the atmosphere) presents many advantages, including permitting stochastic operation by varying the significant meteorological parameters.

The deterministic solution is consistent with the engineering of the energy conversion system, due to its low steady-state mode and the large number of design variables. It is attractive, because of the worldwide dearth of solar energy fluxes data, unlike standard meteorological measurements such as pressure, temperature, relative humidity, etc. The measurement of most of these meteorological parameters is standardized; the instrumentation and techniques of measurement are simple and economical; a considerable amount of historical data are available. The only exception is data on clouds which are important in determining the radiative equilibrium of the Earth. The model calculates their presence through an optical thickness and albedo computation.

Finally, the deterministic approach permits an hour-to-hour match of solar energy fluxes with load (i.e., cooling and heating loads). This is critical for load profiles analysis (e.g., analysis of the utility load duration curve for homeostatic pricing).

The model's precision appears comparable to the precision of the solar energy flux measurements, which are affected by errors and "local" effects that distort their real information content. An increase in precision is theoretically possible, i.e., the phenomena involved in the selective interaction of electromagnetic solar flux and the components of the atmosphere may be described, in a relatively simple way, by the classic physics approach, but the information needed to perform the calculation is not available.

A block diagram of the model is presented in Figure 1 (page 144); a block diagram of the subroutines is presented in Figure 2 (page 145).

Data Base

The data base is a set of meteorological values, generally available for most countries of the world. The quantity and type of data required are determined in the interaction part of the code, where the type of climatic approximation is set by the user (or imposed by the program, should the data furnished by the user be insufficient).

For the U.S., the meteorological data furnished on SOLMET* (in computer-readable form), and on the Surface Weather Observation Chart: Form MF1-10B (in analogic form) are available from U.S. Department of Commerce, Environmental Data Service, National Climatic Center, Ashville, North Carolina.

Computer Aspects of CIRR2

The CIRR2 program is interactive, i.e., as the program executes, it prints running instructions at the user's terminal and queries the user for information needed, such as choice of climatic option. When the program has acquired all necessary option information, it executes the model and the simulation run is complete.

The CIRR2 model is stored as a source program and several data sets. The source program consists of a main program along with several subroutines, all written in FORTRAN. The data sets contain meteorological data for different regions of the U.S.; the user has the option of using a data set containing hourly meteorological data for a particular location. Data sets are stored in a FORTRAN compatible format. Details of data set format and documentation on the model's options and capabilities can be found in the forthcoming CIRR2 User's Manual, available at the M.I.T. Energy Laboratory, or by simply running the program (the input data set format is part of the running instructions).

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*See Section ___ for a description of SOLMET.

A simulation run consists of creating a load module from the source program and running it. The program interactively requests needed information, then proceeds to run the model.

The program is currently implemented on an IBM VM/370 computer with the Conversational Moniter System (CMS) operating system. Since the program is interactive, it requires a large amount of main ("core") storage; specifically, it requires slightly less than 1 megabyte (1024 k-bytes). The source code is transportable, i.e., it can be run on almost any large computer with a FORTRAN compiler. The requirements for a host computer to run CIRR1 include at least 1 mega-byte of main ("core") memory and interactive capability; the model cannot be run easily as a "batch" job.

All of the data required for running CIRR1 are currently stored on disks on the host computer. When the source code is transported from computer to computer, usually via magnetic tape, the required data sets are supplied along with the programs.

6.3 APPLICATONS AND PLANNED FUTURE DEVELOPMENT

The engineering of Solar Energy Conversion systems requires the knowledge of both the values and the dynamics of variation of the design parameters. The latter is information of paramount importance to the engineering optimization of the system, since the system's components and design employ classical non-steady state conditions of operation design (transient operation mode). The variations caused by this operation on some of the design variables may induce critical conditions of system operation (when approaching a limiting curve of component operation) and strongly affects the reliability and efficiency of the system.

Furthermore, these characteristics of the Solar Energy Conversion Systems affect not only the engineering, but also the economics of the system. They are important and should be considered in any energy policy analysis, since they impose certain limitations on the output of the conversion systems.

The goal of this research is to furnish the engineer and the economist with a reliable model of the conversion path of the radiative solar energy flux, i.e., furnish the energy output from any solar energy conversion system, for any location, and for any amount of time. This will be accomplished in 1981.

6.4 LIST OF WORKING PAPERS, ARTICLES AND BOOKS (generated by the project)

1. Russo, G., "Analytical Model and Simulation Codes for the Solar Input Determination: Irradiation Maps," Journal of Solar Energy 21, 1978, pp. 201-210.

This paper provides an outline of the methodlogy adopted in the model.

2. Russo, G., "Solar Energy Conversion Systems Engineering and Economics Analysis: Input Definition," Massachusetts Institute of Technology Energy Laboratory Technical Report No. MIT-EL 73-032, Vol. 1, 1973.

This Technical Report provides a detailed analysis of the physical model.

3. Russo, G., "Solar Energy Conversion System Engineering and Economics Analysis: Input Definition," Massachusetts Institute of Technology Energy Laboratory Technical Report No. MIT-EL 73-033, Vol. 2, 1973.

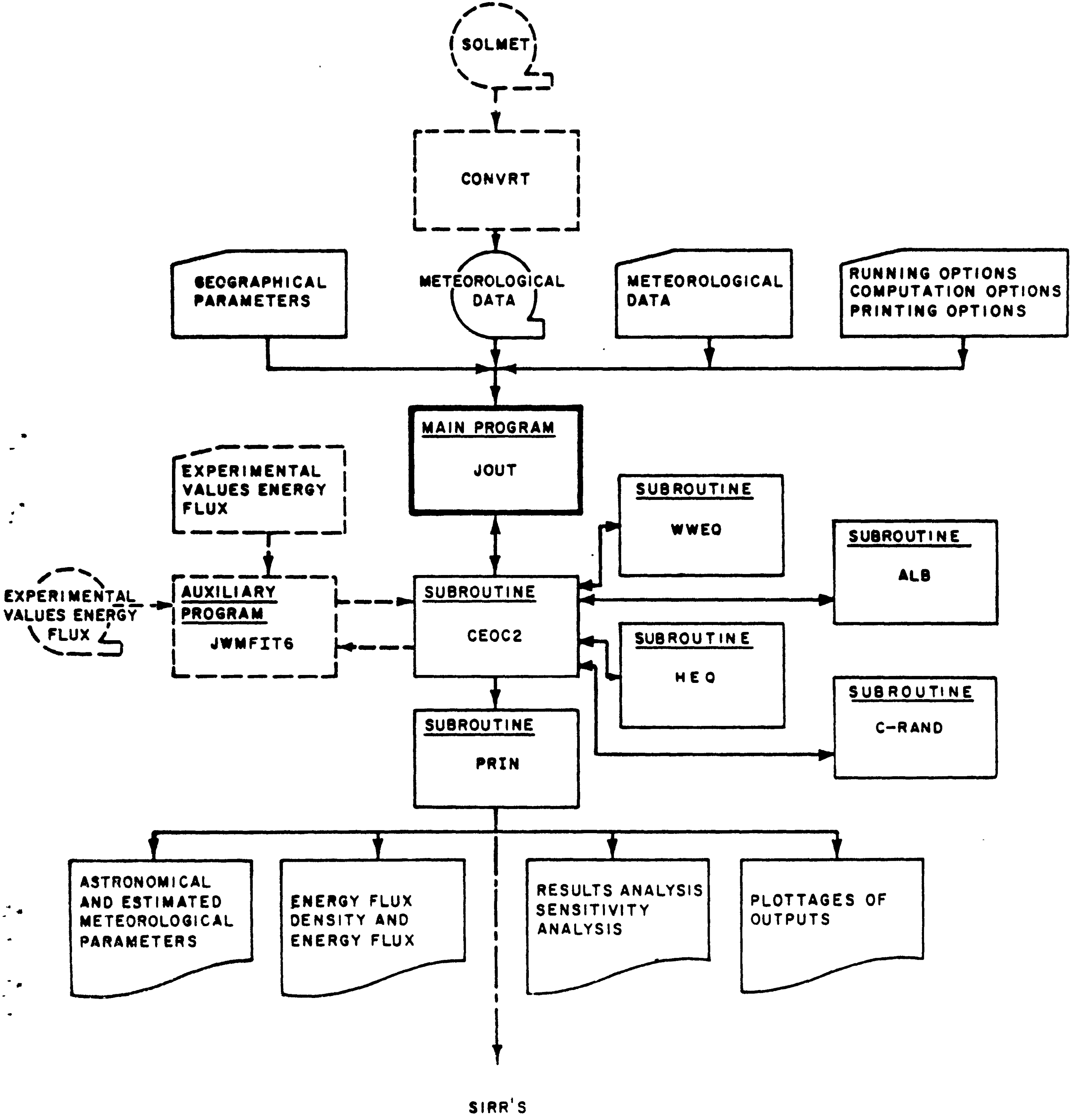
This Technical Report provides a first analysis of the results.

4. Russo, G., "Solar Input and Solar Data Computation for the Engineering of Solar Systems: Transients' Simulation," XIV I.E.E.E. International Meeting of Photovoltiacs Specialists, San Diego, CA, 1980.

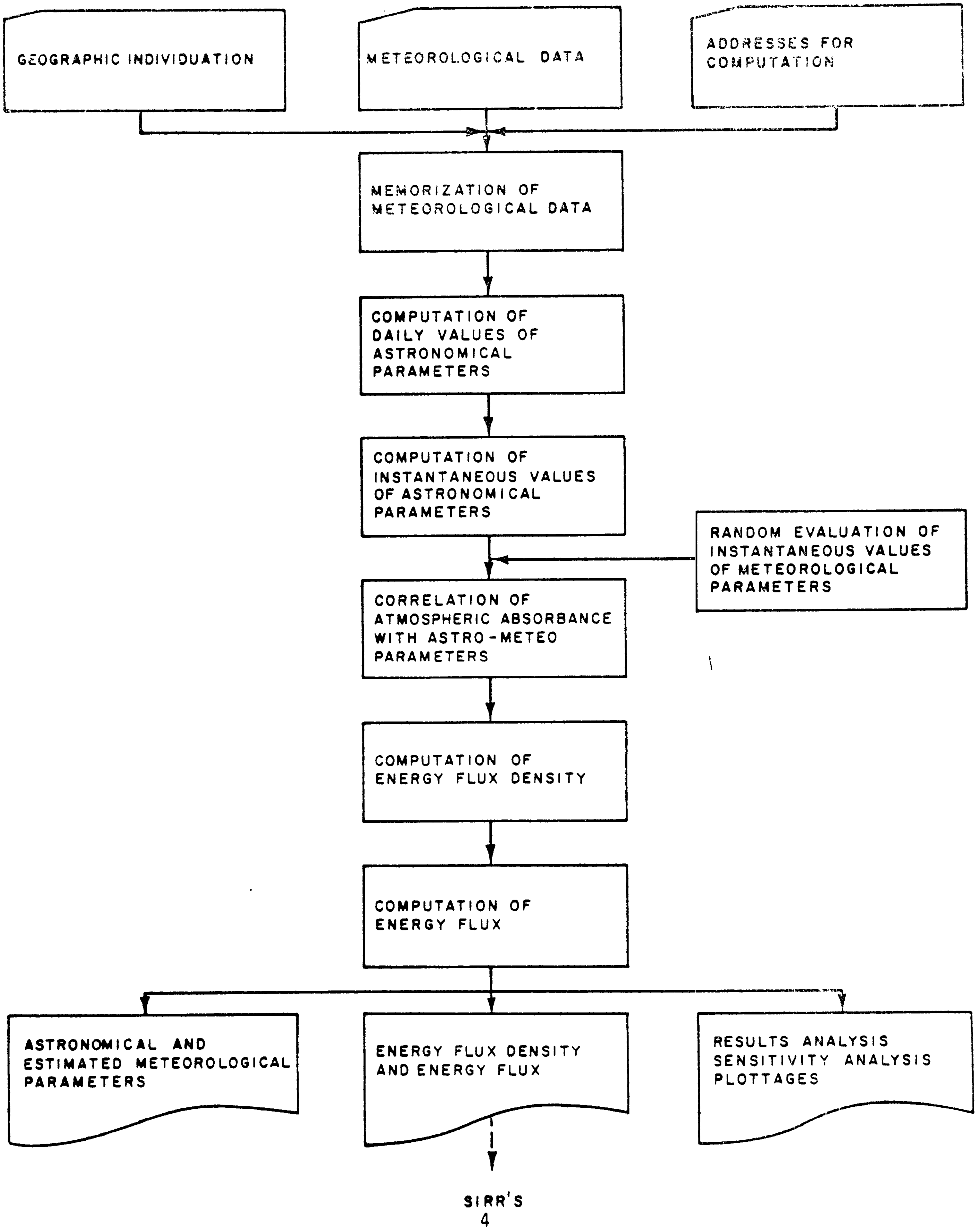
This paper provides a first application of the results and shows their importance.

5. Forthcoming: Four volumes of Technical Reports will furnish a detailed and complete analysis of the set of codes and of their use in the engineering and economic analysis of Solar Energy Conversion Systems. An operating manual will also be prepared.

CIRR 2
BLOCK DIAGRAM
(SUBROUTINES)



CIRR 2
BLOCK DIAGRAM



7.1 MODEL HISTORY

a. Name: Utility Financial/Regulatory Analysis Model (FINREG)

b. Developers: Richard D. Tabors, Peter C. Klosowicz, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: January 1981 - continuing

d. Location: MIT Energy Laboratory, Cambridge, Massachusetts

e. Sponsor: Department of Energy

f. Contact: Peter C. Klosowicz

7.2 MODEL DESCRIPTION

a. Summary

FINREG is a long-range financial/regulatory model that forecasts the financial and regulatory impacts of any electric utiity's capacity expansion plan. The model simulates a utility's yearly revenues, expenses, financing requirements, and actual financing. FINREG also includes a rate-setting submodel that simulates the regulatory environment to generate an average electricity price for the current or future year, and the allowed rate increase.

Two key outputs are generated for each plan from FINREG on a year-by-year basis:

1. Cash generated from operations
2. The average price of electricity

The generation of cash flow allows the user to perform a valuation analysis (i.e., an NPV analysis) for various plans. The user also can examine the effect of any plan on the growth in the average cost of electricity. The model also can be used to generate revenue requirements for rate cases and various accounting variables.

b. Data Base

Data generated from the capacity expansion model EGEAS* provide yearly forecasted cost information for FINREG. However, data generated from any capacity expansion model can be used. The data base also includes additional financial and regulatory data, including current plant tax and book depreciation schedules, investment tax credit (ITC) status, construction financing outlays, capital preferences, base year

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*See Section __, Item ___ for a description of EGEAS.

accounting information, and sales growth. Since rate-setting methodology varies between regulatory jurisdictions, the model requires information on the following regulatory options:

- o automatic adjustment clauses
- o frequency of rate cases
- o the length of regulatory lag
- o inclusion or exclusion of CWIP in rate base
- o the treatment of AFDC
- o normalization or flowthrough of deferred taxes

c. Computer Aspects

FINREG is being developed on the MIT IBM VM/370, in the CMS interactive system, in FORTRAN IV.

7.3 APPLICATIONS AND PLANNED DEVELOPMENT

FINREG will be used by the MIT Utility Systems Program to evaluate the rate and financial consequences of load modification for a particular utility. The model will also serve as a tool in comparing average and marginal costs of electricity. The model may additionally be used for regional electricity analysis.

7.4 LIST OF WORKING PAPERS, ARTICLES, AND BOOKS (generated by the FINREG modeling project)

Klosowicz, Peter C., "The Application of Finance Theory to Issues in Electric Utility Corporate Finance," forthcoming MIT Energy Laboratory Working Paper.

This paper discusses the application of finance theory to such topics as "dilution," regulation, and investment strategy.

8.1 MODEL HISTORY

a. Name:	Electricity Rate-Setting Model (ERATES)
b. Developers:	Alan J. Cox, Richard D. Tabors, Susan Finger, Alan Burns, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c. Duration:	June 1979 - continuing
d. Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e. Sponsor:	Department of Energy
f. Contact:	Alan J. Cox

8.2 MODEL DESCRIPTION

a. Summary

ERATES is designed to estimate electricity rates for a utility system using information on the utility's annual operating costs and its investment history. Fuel costs and plant-specific operating costs are estimated by SYSGEN (see Section 2.4). The rates estimated are for two classes of customers: residential and commercial, and industrial.

Both classes share the total fuel cost of producing electricity, allotted by the proportion of electricity consumed. The capital cost of generating plants is shared in the same manner. However, the capital costs of transmission and distribution facilities are assigned to each class according to the cost of providing these systems to meet each class's requirements. Overhead and billing costs are estimated separately for each class.

Five different types of rates are estimated. These can be divided into two groups. The first are those rates based upon a regulated rate of return allowed on the utility's past investments (referred to as its "embedded" costs). The second set of rates is based upon an annual fixed charge rate applied against the "replacement" value of the utility's capital stock. These replacement rates are used as an approximation of long-run marginal costs, such as those for FINREG.*

Description of Rates

Flat Embedded Rates

This rate establishes a single price for electricity consumed by each of the two classes for all time periods. Each plant is depreciated

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*See Section 3.7.

on a straight-line basis to the year for which the calculation is being made, as is the stock of transmission and distribution equipment. The total undepreciated stock of capital is the "rate base," which is multiplied by the "allowed rate of return." This product plus financing, fuel, and tax costs make up the required revenue for each class. Dividing through by total sales to each class gives the average cost per kilowatt-hour.

Non-Allocated Time-of-Day Embedded

This system estimates peak and base hours for two time-of-day periods and then recovers all capital costs during the peak periods. Thus, the capital costs are estimated as in the flat embedded rate method above and then divided by sales to each class in that period. The average fuel cost is estimated for each period. For the base period, this is added to the per-kilowatt-hour operating and overhead costs. For the peak period these variable costs are added to the average capital costs.

Peak periods are estimated from the number of hours that "peaking" plants are producing power.

Allocated Time-of-Day Embedded Rates

Fuel and other variable operating costs are estimated as for the non-allocated time-of-day method. Capital costs are estimated under the regulatory formula but with "peak" and "base" capital costs estimated separately. The base capital costs are then allocated to the time-of-day periods by multiplying these costs by

$$\frac{Q(t)}{Q(T)}$$

where $Q(t)$ is the amount of electricity generated by base plants during the time-of-day period t, (t = base or peak) and $Q(T)$ is the total production by base plants over the year.

Replacement Flat Rates

Fuel and other variable costs are estimated with the flat embedded method. Capital costs are based upon the current year value (or replacement cost) of all plants. These are multiplied by a proportion, the capital recovery factor. This is equal to the proportion of the replacement value that will have to be recovered over a new plant's life in order to recover its total cost. This cost is constant in real terms and takes full account of taxes, discount rates, and interest payments. The fuel, operating, and capital costs are divided through by total sales to each customer class to estimate a rate. This rate is applied to all time periods.

Replacement Allocated Time-of-Day

This is a version of the allocated time-of-day method of rate setting differing only in the manner in which the capital costs are

9.2 MODEL DESCRIPTION

a. Summary

PV1 is a discrete-time deterministic computer model used to evaluate government policy options in terms of their relative effectiveness in simulating the photovoltaic (PV) market.

Figure I-1 describes the basic idea behind the model. Government actions such as price subsidies and market development make photovoltaics more acceptable in the market by directly lowering the price to the consumer, making more consumers aware of photovoltaics, and instilling confidence in photovoltaics as a technically viable and economic energy technology. Other government actions, such as investments in technology development (TD) and advanced research and development (AR and D) are expected to enhance the basic production technologies for photovoltaics, thereby approaching the DOE goal of $1.60 per peak watt.

The more rapidly photovoltaics is accepted in the market, the higher the purchase rate. As the production industry takes advantage of increasing economies of scale, the unit costs should decline, further increasing the market acceptance rate for photovoltaics.

This model starts with a market potential that is sector and region specific. The potential market acceptance rate is reduced by PV characteristics, particularly cost, but also by perceived risk and other product characteristics.

The model includes several important controls and feedbacks. The purchase rate diminishes the potential market. It also lowers PV cost through production experience. The government can lower PV cost directly, through some type of subsidy, or indirectly:

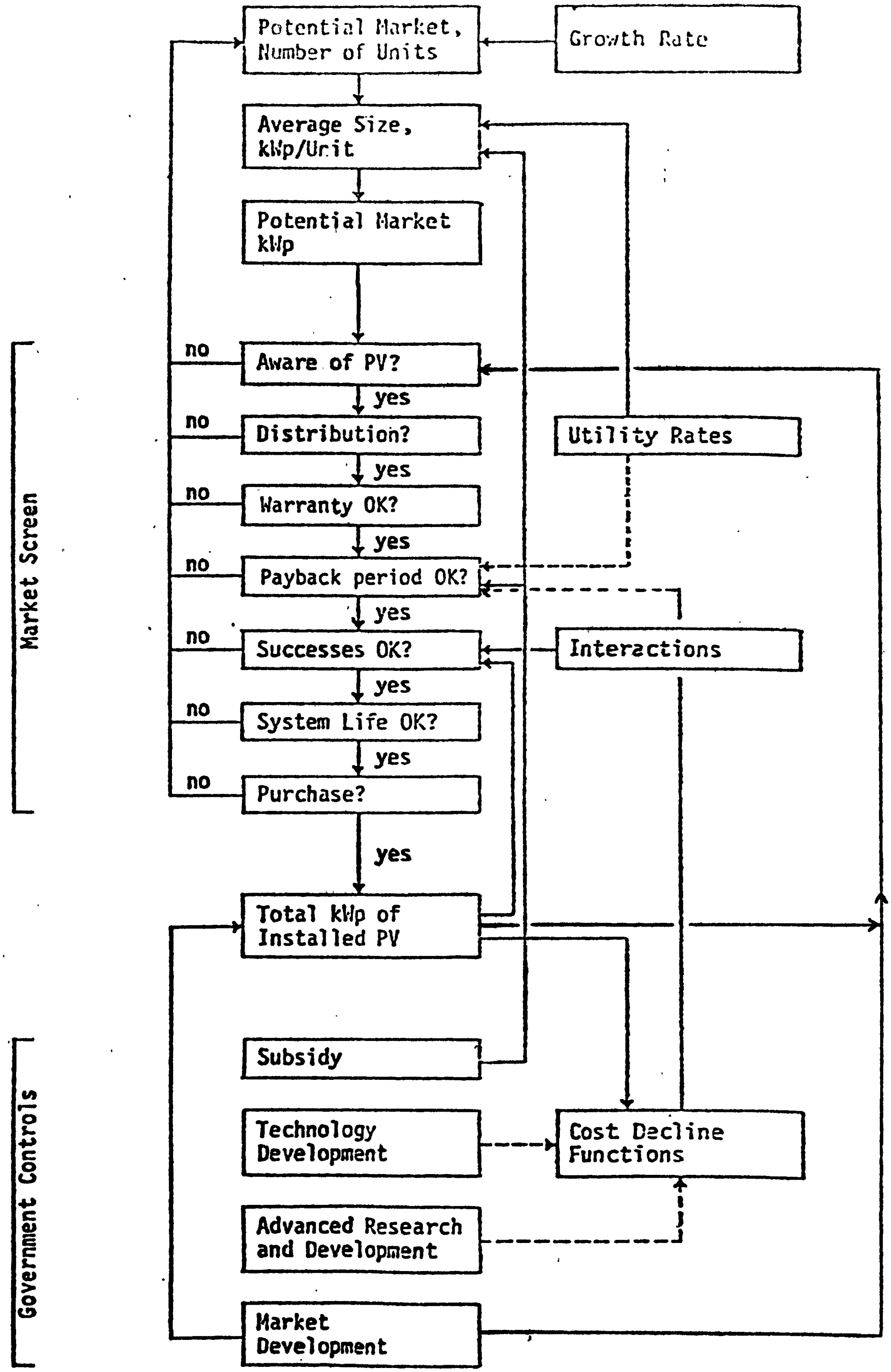
(a) through market development expenditure--the government 'buys,' for demonstrations--lowering production costs through production experience; or

(b) R and D or Technology Development spending, which are funds spent to improve production processes or to develop newer, lower-cost PV materials.

To implement PV1, the user must:

1. Select from a specified list those sectors of the economy to be analyzed;
2. Determine the planning horizon of the model in years; and
3. Define government programs in terms of levels of support, and allocate this support over sectors and regions.

Exhibit 2.3 PV1 Model Structure



In turn, PV1 will provide the user with output regarding peak kilowatts of PV installed by year and by sector, and the cost of government programs. This last output is not simply an echo of the user's input because the spending for subsidies will not be known until after the level of market penetration is determined.

b. Data Bases

The data bases used by PV1 are derived from a number of sources and include solar radiation (from SOLMET data*); number of customers in each of the sectors in the potential market; average cost per kilowatt hour; customer demand (from *Statistics of Privately Owned Electric Utilities in the United States* and *Statistics of Publicly Owned Electric Utilities in the United States*); *and the cost of the least kilowatt hour of electricity purchased* (from *The National Electric Rate Book*).

c. Computer Aspects of the Model and Data Base

The data reside both on the MULTICS computer (along with PV1) and on the IBM VM/370 at MIT. PV1 is written in PL/1 on the MULTICS computer at MIT. It is an interactive model that is intended to be user oriented. Until validation and verification are completed, prospective users should contact the authors to suggest policy scenarios to be submitted to PV1. Once the validation and verification efforts have been completed, the model will be available for outside use.

9.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENT

Future development of PV1 is expected to allow greater flexibility in applying the model for policy analysis. Statewide policies that parallel federal policies will be incorporated, so the effects of subsidies of various types among the states may be tested. Also, the effects of income level and taxation will be included in subsequent versions of the model. The impacts of alternative utility rate structures on PV economics will also be included.

Most other modifications to PV1 will involve improvements in the accuracy of the data bases, including improved solar radiation data and improved data relating to industrial, commercial, public authority, and agricultural sectors. Additional changes will involve the variables and format of the output provided by PV1. This will include the computation of indices for the comparative evaluation of policies, and the possible use of computer graphics for output variables.

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*SOLMET is a collection of U.S. regions' insolation and collateral meteorological data compiled by the National Climatic Center. It is more fully described in Section IV, item 4.

9.4 LIST OF WORKING PAPERS, BOOKS AND ARTICLES (GENERATED BY THE PV1 PROJECT)

The PV1 User Documentation is as yet unpublished, but draft copies are available from the authors at MIT.

IV. FREE-STANDING DATA COLLECTIONS

1.1 MODEL HISTORY

a.	Data Collection:	Energy Macro Data Base
b.	Developers:	Knut A. Mork and associated students, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c.	Duration:	1976-present
d.	Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e.	Sponsors:	Center for Energy Policy Research and the National Science Foundation
f.	Contact:	Knut A. Mork

1.2 DATA DESCRIPTION

a. Summary

This data collection contains price and quantity inputs and aggregate outputs of the non-farm, non-energy (i.e., excluding coal, oil, and gas extraction) sector of the US economy, for the years 1947-1975. The inputs are labor, capital, energy, and agriculture. The data, the sources used in compilation, and the present computer storage are described below.

Sectoral Input Data

Labor

Hourly compensation and hours worked of all persons for the private non-farm sector were obtained from the US Bureau of Labor Statistics. Time series on man-hours, average hourly earnings, and compensation per man-hour were constructed, in addition to both straight wage indices and Divisia wage indices, the latter to correct for overtime and inter-industry shifts in employment. The data are in both quarterly and annual form.

Annual series for compensation and hours worked by employees in the coal-, oil-, and gas-extraction subsectors were used to compute compensation per man-hour in the energy sector. These series were obtained from National Income and Product Accounts publications. Quarterly figures were constructed by linear interpolation. A time series for hours worked by all persons engaged in production in the energy sector was also constructed, utilizing information available on persons engaged in production in the mining sector.

Data on compensation and hours worked in the goods sector were obtained as a residual category, using the total available from the US Bureau of Labor Statistics, net of the energy sector.

The Bureau of Labor Statistics' "Employment and Earnings, 1909-1972" and monthly issues of Employment and Earnings were used to construct the series on average hourly earnings of production and nonsupervisory workers on private non-agricultural payrolls. The index, which adjusts for interindustry shifts in employment, uses as weights the product of the number of workers in several divisions of industry and the average weekly hours for the same categories of workers in each industry. Series were also created for the transportation and public utilities sectors.

Capital

Gross investment in the goods sector was obtained from specific categories in the National Income and Product Account Tables. Quarterly series were constructed, assuming gross investment fluctuates quarterly like total private fixed investment. A quarterly series of real capital was then constructed, benchmarked to 1974:1, using data from the Survey of Current Business.

Agriculture

Monthly series were constructed from data in Farm Income, published by the US Department of Agriculture and converted to a quarterly basis. The data in Farm Income consist of receipts from marketing and CCC loans, excluding government payments. Imports were added and exports excluded. The data were obtained from publications of the US Bureau of the Census on foreign trade. The WPI for farm products was chosen as the input price for agricultural goods.

Energy

Inputs to the goods sector of quantities of petroleum, natural gas, natural gas liquids, coal, and hydroelectric and nuclear power were compiled. The sources used include the Bureau of Mines' Minerals Yearbook, the Survey of Current Business, and press releases of the FPC. A price index using quantities as weights was constructed from the WPI of crude petroleum and coal, with some adjustments.

Output

Gross output and price of output of the goods sector were constructed from National Income and Product Accounts data and the various sources described above. The components used in the construction were: GNP originating in the business, non-farm sector, plus the household sector, net of the energy sector. The prices of deliveries to agriculture and energy were also used to compute the value of output.

b. Computer Aspects

All data are currently stored on-line as one- or two-dimensional time series on the TROLL system of the MIT IBM VM/370.

2.1 MODEL HISTORY

a.	Data Collection:	Interfuel Substitution
b.	Developer:	Chris Alt, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
c.	Duration:	1979-1980
d.	Location:	MIT Energy Laboratory, Cambridge, Massachusetts
e.	Sponsor:	MIT Center for Energy Policy Research, Cabot Fellowship
f.	Contact:	Chris Alt, Jacqueline Carson

2.2 DATA DESCRIPTION

a. Summary

U.S. data on industrial energy consumption have been compiled from public sources for the years 1958, 1962, 1967, 1971, and 1974. The data are disaggregated by state and by 2-digit SIC codes 20-39. The data collection includes cost and quantity of fuel consumed.

Cost and quantities of the following four fuel categories are included: bituminous, anthracite, and lignite coal and coke and breeze; natural gas; purchased electricity; and fuel oil (distillate and residual). The units used are thousand tons, millions of cubic feet, million kWh, thousands of barrels, or for the cost series, thousands of dollars. The sources used were the Census of Manufacturers, which comes out every five years, and the Annual Survey of Manufacturers for the intervening years.

b. Computer Aspects

The data are currently stored on verified cards available at the MIT Energy Laboratory. A FORTRAN program has been developed to read the data, which are also stored on cards and are available at the Laboratory. Hard copy printouts of both the data and the program are available.

2.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENTS

There are no current plans to further utilize or develop this data collection.

2.4 REFERENCES

Alt, C., "Interfuel Substitution Issues, PhD Dissertation, forthcoming.

3.1 MODEL HISTORY

a. Data Collection: OESYS Model, Related Data Collection; SOLOPS

b. Developers: Dr. Richard Tabors, Alan Cox, and Tom Dinwoodie, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

c. Duration: No termination date

d. Location: MIT Energy Laboratory Utility Systems Program/Photovoltaics Project, Cambridge, Massachusetts

e. Sponsor: OESYS is part of a larger project funded by the Department of Energy to study the commercialization of Solar Photovoltaics

f. Contact: Tom Dinwoodie

3.2 DATA DESCRIPTION

a. Summary

Hourly or sub-hourly load profile data were obtained by surveying a number of utilities nationwide. The data are a compilation of meter data (for periods of three to four years) and were provided by the utilities as either hard copy or magnetic tape. These data are now being developed for use by the OESYS model, which involves processing both the machine readable and hard copy material for compatability with the model.

Data are available for four regions--Phoenix, Boston, Madison and Tampa--and as of 5/80 there are approximately 100, 20, 75 and 0 accounts that are OESYS compatible for these four cities, respectively. The data are reported for specific end-user classes (by SIC code) such as manufacturing, agriculture, trade, and various residential and commercial units.

b. Computer Aspects

Software

Software developed to process the data is available and documented in internal memoranda. The programs developed handle the conversion into CMS compatible format, provide an organized filing scheme, format the data for compatability with OESYS, and analyze the data for bad data points and gaps.

Storage

The raw data (tape and hard copy) are presently stored at the MIT

Energy Laboratory and at the MIT IPS library. The OESYS compatible data are stored on tape at IPS. The technical information required to read the tape is in the form of internal notes and memoranda.

3.3 PLANNED FUTURE MODEL AND DATA DEVELOPMENTS

See OESYS Model section.

3.4 REFERENCES

Cox, A.J., "The Economics of Photovoltaics in the Commercial, Institutional, and Industrial Sectors," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January, 1980.

This paper describes the application of a model that computes system break-even capital costs, array break-even capital costs, and profits from photovoltaic investments in the industrial, commercial, and institutional sectors. Several tax and accounting combinations are described and utilized in this paper. Results indicate that, at rates of return usually found in the industrial and commercial sectors, photovoltaic investments will not be attractive when the costs of those investments are based on the Department of Energy's cost goals for 1986.

Millner, A.R. and Dinwoodie, T., "System Design, Test Results, and Economic Analysis of a Flywheel Storage and Conversion System for Photovoltaic Applications," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January 1980.

MIT Lincoln Laboratory is developing a flywheel interface and storage system for use with photovoltaic power sources. Test data on the performance of components built to investigate the feasibility of such a system, and the results of economic studies of the system showing user-worth analysis and manufacturing-cost estimates, are presented. The system has magnetic bearings, a maximum-power-point tracker, DC input, and cycloconverter output from an ironless-armature motor-generator.

Dinwoodie, T.L., "Flywheel Storage for Photovoltaics: An Economic Evaluation of Two Applications," MIT Technical Report No. MIT-EL 80-002, February 1980.

A worth analysis is made for an advanced flywheel storage concept for tandem operation with photovoltaics currently being developed at MIT/Lincoln Laboratories. The applications examined here are a single-family residence and a multi-family load center, 8 kWp and 100 kWp, respectively. The objectives were to determine optimal flywheel sizing for the various operating environments and to determine the financial parameters that would affect market penetration. The operating modes included both utility interface and remote, stand-alone logics. All studies were performed by computer simulation.

The analysis concludes that flywheel systems are more attractive in residential applications, primarily because of differences in financing parameters and, in particular, the discount rate. In all applications flywheel storage is seen to increase the optimal size of a photovoltaic system. For stand-alone environments, optimum configuration sizing is fairly insensitive to hardware cost of photovoltaics and flywheels for a given reliability when no diesel generator is included.

4.1 MODEL HISTORY

a. Data Collection: OESYS Model, Related Data Collection; SOLMET

b. Developers: National Climatic Center

c. Duration: No termination date

d. Location: MIT Energy Laboratory Utility Systems Program/ Photovoltaics Project, Cambridge, Massachusetts

e. Sponsor: OESYS is part of a larger project funded by the Department of Energy to study the commercialization of Solar Photovoltaics

f. Contact: Tom Dinwoodie

4.2 DATA DESCRIPTION

a. Summary

FORTRAN compatible tapes that provide quality-controlled hourly solar insolation and collateral meteorological data compiled by the National Climatic Center (NCC) have been obtained for Phoenix, Boston, Madison, Tampa, Omaha, Fort Worth, and Miami. As available to our researchers, the SOLMET tapes represent an effort to eliminate the errors resulting from neglectful maintenance and calibration and instrument problems that previously plagued this historical database. The data are now available in metric units for hourly solar radiation and hourly surface meteorological observations. The data can be accessed in true solar and local standard time. Some additional solar radiation parameters may be available.

b. Computer Aspects

Software

The modelers have developed programs that convert the data to direct and diffuse insolation values compatible for use in the photovoltaic simulation aspect of the OESYS model.

Storage

The NCC provides a format description and a technical tape descriptor, which is now on file at the MIT Energy Laboratory. The tapes are stored in IPS tape slots. The records and documentation are available in internal files and memoranda only.

4.3 APPLICATIONS AND PLANNED FUTURE DEVELOPMENTS

See OESYS Model in Section IV.

4.4 REFERENCES

Cox, A.J., "The Economics of Photovoltaics in the Commercial, Institutional, and Industrial Sectors," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January, 1980.

This paper describes the application of a model that computes system break-even capital costs, array break-even capital costs, and profits from photovoltaic investments in the industrial, commercial, and institutional sectors. Several tax and accounting combinations are described and utilized in this paper. Results indicate that, at rates of return usually found in the industrial and commercial sectors, photovoltaic investments will not be attractive when the costs of those investments are based on the Department of Energy's cost goals for 1986.

Millner, A.R. and Dinwoodie, T., "System Design, Test Results, and Economic Analysis of a Flywheel Storage and Conversion System for Photovoltaic Applications," presented at the IEEE Photovoltaic Specialists Conference, San Diego, CA, January 1980.

MIT Lincoln Laboratory is developing a flywheel interface and storage system for use with photovoltaic power sources. Test data on the performance of components built to investigate the feasibility of such a system, and the results of economic studies of the system showing user-worth analysis and manufacturing-cost estimates, are presented. The system has magnetic bearings, a maximum-power-point tracker, DC input, and cycloconverter output from an ironless-armature motor-generator.

Dinwoodie, T.L. "Flywheel Storage for Photovoltaics: An Economic Evaluation of Two Applications," MIT Technical Report No. MIT-EL 80-002, February 1980.

A worth analysis is made for an advanced flywheel storage concept for tandem operation with photovoltaics currently being developed at MIT/Lincoln Laboratories. The applications examined here are a single-family residence and a multi-family load center, 8 kWp and 100 kWp, respectively. The objectives were to determine optimal flywheel sizing for the various operating environments and to determine the financial parameters that would affect market penetration. The operating modes included both utility interface and remote, stand-alone logics. All studies were performed by computer simulation.

The analysis concludes that flywheel systems are more attractive in residential applications, primarily because of differences in financing parameters and, in particular, the discount rate. In all applications flywheel storage is seen to increase the optimal size of a photovoltaic system. For stand-alone environments, optimum configuration sizing is fairly insensitive to hardware cost of photovoltaics and flywheels for a given reliability when no diesel generator is included.

5.1 MODEL HISTORY

a. Data Collection:	Energy Model Data Base
b. Developers:	Brookhaven National Laboratory
c. Duration:	Not applicable
d. Location:	MIT Energy Laboratory, Cambridge, Massachusetts; Brookhaven National Laboratory, Upton, New York
e. Sponsor:	Brookhaven National Laboratories under contract with the United States Energy Research and Development Administration and the United States Atomic Energy Commission
f. Contact:	Jacqueline Carson

5.2 DATA DESCRIPTION

a. Summary

The Energy Model Data Base developed at Brookhaven National Laboratories is a model-independent computerized data collection. A copy of the data base is available at the MIT Energy Laboratory. The data and the present storage format are described below.

The data collection and the software developed to support it are independent of any particular model. It does, however, reflect the requirements of the National Center for Analysis of Energy Systems at Brookhaven, providing a descriptive overview of the technological aspects of the U.S. energy system.

The data base is structured to represent the flow of energy through the energy system, capturing numeric quantities at five levels:

1)	element -	a quantity, or cost
2)	process -	technological operation, e.g., steel production by electric furnace
3)	activity -	system component, e.g., electricity generation
4)	trajectory -	a linked series of processes, e.g., offshore oil extraction to freight transportation by diesel truck
5)	subsystem -	related trajectories, e.g., coal extraction to all coal uses

The relational nature of the database can best be conveyed by the diagram in Figure 1 (see page 169), taken from a Brookhaven report. Activities are identified at the top of the page, and processes are identified on the trajectory links.

Scope of the Data

The data base includes 635 supply processes for current technologies and 180 supply processes for future technologies. Demand for fuels is represented by 220 processes for fuel-specific end-use demands. The residential, commercial, industrial, and transportation sectors are included in end-use demand.

Examples of activities, processes, and elements included in the database are shown below. This is by no means an exhaustive list, but is provided here to give the reader a better idea of the type of information available.

Examples of Activities, Processes, and Elements

End-Use Sector	Activity	Process
residential	lighting	incandescent light fluorescent light yard light
commercial	lighting	indoor lights streetlights
industrial	SIC 28	inorganic chemicals organic chemicals
transportation	passenger	domestic airlines urban bus motorcycle recreation boat

Elements

efficiency factors
water emissions
air emissions
solid waste and land use

Documentation

A reference number is associated with each data element, which refers the user to the source used. A footnote number is also associated with each data element. The footnotes are textual descriptions of calculations, assumptions, etc. used in deriving the element. The compilers of the data have also included a measure of quality for the data elements, ranging from one to five, which will give the user an indication of how reliable the researchers felt the data point to be. Their criteria are included in the footnotes to the computer data files.

b. Computer Aspects

A copy of the Energy Model Data Base is available at the MIT Energy Laboratory on magnetic tape. The footnote files are included on the tape. The technical information received to read the tape is also available, along with a user's guide. "People readable" materials are also at the MIT Energy Laboratory, in the form of computer printouts and microfiche.

Brookhaven has not maintained the data base for several years. The reference files do not appear to be included; it is not possible to list the sources at this time. Since the tapes are also in "people readable" format, programming expertise is required to manipulate the data for modeling or estimation. Also, a "relational" data base is rare and may be of limited utility for this reason.

5.3 PLANNED FUTURE DEVELOPMENTS

No development of this data is planned.

5.4 REFERENCES

Goldberg, M.D., *Energy Model Data Base User Manual*, Brookhaven National Laboratory, BNL 19200.

This document describes the data base and the programs written for creating or maintaining the same.

Goldberg, M.D., Sevian, W.A., Reisman, A.W., and Newhouse, P., "The Energy Model Data Base Program," Informal Report BNL 21545, June 1976.

This paper states the rationale for creating the energy model data base and describes its contents.

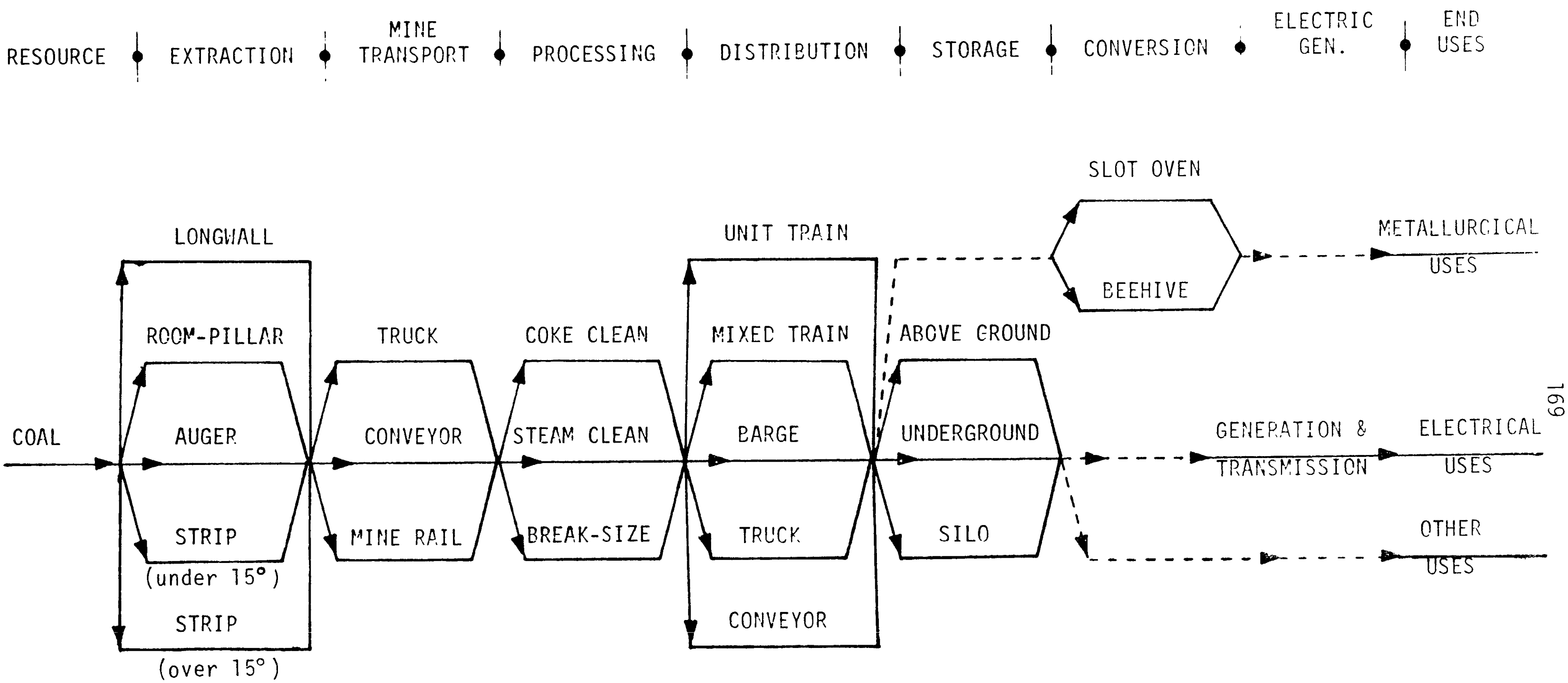

FIGURE 1. COAL SUPPLY SUBSYSTEM

APPENDIX: RESPONSE FORM

Please send the completed response form to:

Ms. Jacqueline Carson
E38-410
Energy Laboratory
Massachusetts Institute of Technology
Cambridge, Mass. 02139

RESPONSE FORM*

1. Do you have any comments on the content and format used for the model and data descriptions in the directory?

   Are there other elements not presently included which would be helpful (please specify)?

2. Do you find the Data and Model Directory useful?

   ☐ Yes ☐ No

   Please explain

3. Are you interested in any specific model or models and/or data collections included in the directory?

   ☐ Yes ☐ No

   If yes, please name them:

* If space provided is not adequate please feel free to attach additional sheets.

5. Do you feel there is a <u>need</u> for a <u>service oriented</u> Data and Model facility to extend the accessibility of the model and data bases included in our directory?

☐ Yes ☐ No

Please explain and give suggestions:

6. General Remarks:

7. Would any other department of your organization or institution be interested in this directory?

Name:

Department:

Address:

Signature ______________________________

Title ______________________________

Address ______________________________

For what purposes are they of interest to you?

Please specify:

4. Are you interested in accessing any of the above models and/or data collections?

☐ Yes ☐ No

If yes, indicate which models and/or data collection and in what forms.

☐ Obtain descriptive documentation (in terms of E-Lab working papers, books and publications on the relevent model).

Model Name(s)/Data Collection(s)

☐ Obtain technical documentation (in terms of a program package consisting of computer related material).

Model Name(s)/Data Collection(s)

☐ Obtain technical support from the Energy Laboratory staff.

Model Name(s)/Data Collection(s)