ENERGY LABORATORY

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

CARTEL BEHAVIOR AND EXHAUSTIBLE RESOURCE SUPPLY: A CASE STUDY OF THE WORLD OIL MARKET

(NSF Grant No. DAR 78-19044)

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PROJECT SUMMARY

The M.I.T. World Oil Project has been developing improved methods and data for analysis of the future course of the world oil market. Any forecast of this market depends on analysis of the 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. The resulting net demand for oil from the core members of the oil cartel determines the ability of OPEC to set prices. In the M.I.T. research, study of net demand for cartel oil is accompanied by analysis of the behavior of the price-setters themselves, and exploration of the details of market structure as they influence price behavior and trade patterns.

The work involves a set of studies of oil supply from key producer areas, import demand from consuming nations, integration of supply and demand studies into the overall market analysis, and behavioral studies of the cartel. In the period covered by this report, the focus has been on the further documentation and application of research results from previous years of National Science Foundation support, and the extension of the work in the areas of disaggregated analysis of oil supply, financial influences on supply decisions, and analysis of cartel behavior.

The research contributes to our understanding of the workings of the world oil market and of the likely effects of various national policies. Results include forecasts of likely future price paths, evaluation of various consumer and producer country policies, and study of likely trade patterns in oil and their implications for national security and international finance.

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1. INTRODUCTION

1.1 Project History

Research on the world oil market is being carried out by the M.I.T. Energy Laboratory, Program on International Energy Studies, in association with the Sloan School of Management and the Department of Economics. The work was initiated in Summer 1973, with seed money from the M.I.T. Energy Laboratory. Beginning in March 1975, the project received support from the National Science Foundation for work on "Analysis of the World Oil Market" (NSF Grant No. SIA75-00739). The original grant request was for a 3-year period. Initially, funding was granted for an 18-month period, March 1, 1975 to August 31, 1976. Later, a continuation proposal was approved, providing support for the period September 1, 1976 through February 28, 1978.

Beginning July 1, 1978, an additional two years of work was funded by the National Science Foundation under a project on "Cartel Behavior and Exhaustible Resource Supply: A Case Study of the World Oil Market" (NSF Grant No. DAR78-19044). This report covers that project. Appendix B presents project publications and working papers produced since the beginning of NSF support in 1975.

The work has been led by three co-principal investigators:

M.A. Adelman -- Professor of Economics

Henry D. Jacoby -- Professor of Management and Director of the Program on International Energy Studies, M.I.T. Energy Laboratory

Robert S. Pindyck -- Professor of Management

Over the course of the project several other faculty and M.I.T. staff have contributed. Also, students have played a significant role in the

research; during the period covered by this report, approximately ten graduate students have been employed as research assistants, for periods ranging from a semester to the duration of the project.

1.2 Recapitulation of Research Objectives

U.S. energy policies are strongly affected by developments in world oil supply and demand, and by movements in the oil price. Events in this market play a dominant role in the consideration of measures to stimulate domestic supply or encourage conservation, and in discussions of oil and natural gas price controls, energy taxation, tariffs and quotas, and the national program of energy R&D and commercialization. Expected market structure and supply patterns also impinge on national security and influence the design and management of crude oil stockpiles, oil sharing agreements, and emergency demand control measures.

The objective of the M.I.T. World Oil Project is to lay the foundations for a better understanding of the characteristics of this market, and to develop improved methods and data for analyzing likely developments over the next few decades. The oil market presents a continually evolving challenge to understanding and analysis. Prices and contractual agreements have undergone radical change in the past few years, and even in recent months. The potential capacity for oil production in key areas of the world, and the motivation of governments to produce from it, is a matter of considerable uncertainty and dispute. In the future, additional shocks to the system are likely.

From the outset, the Project has been designed to develop models, supporting data bases, and related analysis to assist policy makers and the public as they make decisions in this area. Examples of the types of analysis our work is intended to support include:

- Analysis of the future level and structure of world demand for energy in general, and for oil in particular.
- Analysis of the supply of oil, taking account of geologic potential, cost and problems of access, and government policy.
- Study of the likely future course of the world oil price.
- Research on the effect of oil investment and export decisions on the macroeconomics and finance of producer countries; and, conversely of the likely macro-financial implications for oil capacity creation and total production and export.
- Study of market structure and trade patterns in oil, and the associated implications for national security, international relations, and the oil revenues and foreign balances of key producer states.
- Analysis of international financial and economic growth problems that may be created by changes in oil price and volume.

The intent has been that the models, data, and associated studies developed by the Project be incorporated into the work of government agencies and private groups who are concerned with this market.

2. SUMMARY AND REVIEW OF WORK TO DATE

During the two-year course of this grant we performed research on a variety of related tasks as outlined in our proposal, and as amended by our letter of April 28, 1978. These tasks were:

- Subtask 1.1.c Continuing Documentation and Transfer of Data, Models and Results
- Task 1.3 Analyses Using Models and Data Developed by the Project
- Subtask 3.1.b Analysis of Producer Tax Systems
- Task 3.2 Further Development of the Disaggregated Model
- Task 3.3 Incorporation of the Influence of Financial Factors on Supply
- Task 4.1 Analysis of Internal Cartel Allocation
- Task 4.2 Analytic Models of Cartel Behavior
- Task 7.1 Portfolio and Supply Decisions by OPEC Countries

This section describes the results achieved under each task. The text includes citations to the publications and working papers produced during the two-year period of this grant; they are listed in Appendix A.

Subtask 1.1.c Continuing Documentation and Transfer of Data, Models, and Results

Our work plan for this task anticipated three working papers and two monographs. We have published two papers, completed five additional working papers, and have completed and published one monograph.

Demand Estimation

The econometric estimation of oil demand by sector in various countries is now completed and is presented in one book, two published

papers, and two additional working papers. "Log Linear Models of Petroleum Product Demand: An International Study" [34] by R. Heide documents and presents the results of the estimation of petroleum product demand, both for major oil consuming countries and other countries whose future consumption is expected to be significant. "The Demand for Motor Gasoline: A Multi-Country Stock Model" [35]* by R. Heide describes a dynamic gasoline consumption model which uses a capital stock model for eleven major consuming countries. This submodel of the transport sector and the product demand equations have been incorporated in our world oil market simulation model.

The complete demand model and overall demand estimation procedure along with a discussion of alternative demand models, methodological issues, and a presentation of statistical results are contained in a monograph by R. Pindyck, The Structure of World Energy Demand [18]. For major oil-consuming countries estimation of demand in residential and industrial sectors are reported in R. Pindyck, "International Comparisons of the Residential Demand for Energy" [23], and in R. Pindyck, "Interfuel Substitution and Industrial Demand for Energy: An International Comparison" [20]. The most promising results for the residential sector came from a two stage indirect translog utility function, estimated with pooled data for nine countries. For the industrial sector the best results were obtained from a two stage translog cost function, estimated with pooled data for ten countries.

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*Numbers in brackets refer to Appendix A. Abstracts of these publications and working papers are provided. At several points in this report reference is made to internal research memoranda; these are not included in Appendix A.

Documentation of the demand data base is complete and is contained in a working paper by J. Carson, "A User's Guide to the M.I.T. World Oil Project Demand Data Base," [29]. This paper describes the data developed for the estimation of the residential, industrial, and transportation sectors, and the product demand data, and discusses some of the methodological problems. This User's Guide has been made available to a number of researchers and organizations, many of which have also received computer tapes of the data base.

Supply Analysis

The supply side of the M.I.T. World Oil Model currently consists of the aggregate analysis framework described and documented in a working paper by M. Adelman and J. Paddock, "An Aggregate Model of Petroleum Production Capacity and Supply Forecasting" [27]. The theoretical development and methodology are presented, and the relationships between geologic and economic characteristics are analyzed, and a system of equations representing the inertial process model are described. Next the construction of the database 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 supply model are presented through 1990.

Development of Model Simulator

As part of the ongoing work of documenting, calibrating, and integrating the demand analysis with the overall simulation framework, we have constructed a model simulator to facilitate access to the program. A core program has been developed which 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 by the model. The command syntax is similar to standard TROLL commands and macros, and it makes available a modifiable base of commands which are automatically implemented without explicit reference, plus an arbitrary number of user-designated, run-specific command options.

This work includes the definition of a set of capabilities available to users. These capabilities can be implemented individually as command option macros--to be included in the base commands or designated explicitly by the user. This approach allows the development of an open-ended set of command options, which will reduce the work needed to enhance capability as ongoing research creates new needs. New commands remain consistent with the set of old commands.

Technical Documentation of Supply, Demand and Integration Models

Documentation of the demand, supply, and integration models, their parameters and methodology, and a user's guide are contained in a working paper by Carson, Christian, and Ward, "The M.I.T. World Oil Model: Documentation and User's Guide" [30]. This paper supplements the User's Guide to demand data, discussed above, and is a working guide for the user of the project's simulation models. It contains a description of the three separate models used by the World Oil Project. The Demand Model forecasts energy demand with crude oil demands from the rest of the world, excluding centrally-planned economies. The supply model forecasts possible production scenarios for oil producers throughout the world. The integration model integrates demand and supply forecasts and allocates actual production to producers. This paper reviews the

estimation methodology and data bases used in constructing the models. The equations are described and the behavior summarized. Policy-analytic use of the model is described and limitations of the model are identified. Sample output is presented and the use of the simulation framework is described.

Dissemination of the Data and Models

A number of individuals and organizations have requested and received various computer tapes of our models and data bases. They include:

1. Center for Applied Research of the Norwegian School of Economics and Business Administration. Summary 1978.

2. Central Bank of Norway. Summer 1978.

3. Project ZENCAP, Center for Economic Research, Swiss Federal Institute of Technology, Zurich, Switzerland. August 1978.

4. Data Resources, Inc., Lexington, Massachusetts 02173. August 1978.

5. Resources for the Future, Ms. Rosamond Katz, 1775 Massachusetts Avenue, NW, Washington, D.C. August 1978.

6. Professor Jacob Zahavi, Faculty of Management, Tel Aviv University, Tel Aviv, Israel. October 1978.

7. Dr. Paul MacAvoy, Yale University, School of Organization and Management, New Haven, Connecticut 06520. November 1978.

8. Mr. Howard Green, Research, Federal Reserve Bank of Atlanta, Federal Reserve Station, Atlanta, Georgia 30303. June 1978.

9. Dr. William Hogan, Kennedy School of Government, Harvard University, Cambridge, Massachusetts 02138. December 1978.

10. Tom Woodward, Box B Economics, Brown University, Providence, Rhode Island 02912. December 1978.

11. Professor E.L. Dougherty, Project Director, Energy Modeling Center, University of Southern California, 3375 South Hoover Street Suite H, Los Angeles, California 90007. April 1979.

12. Dr. Lee Schipper, Laurence Berkeley Laboratory, Berkeley, California 94720. October 1979.

13. Ms. Gwenn Webb, Texaco, Incorporated, 2000 Westchester Avenue, White Plains, New York 10650. January 1980.

Task 1.3 Analyses Using Models and Data Developed by the Project Publications

On this task we have substantially exceeded the output anticipated in the proposal. The original work plan called for two working papers; thus far we have completed eleven and have one more in draft form. All these papers draw in some measure on the simulation results from the M.I.T. World Oil Model and the supporting analysis. Four papers use the overall supply/demand simulation framework. They are: M. Adelman, "World Supply and Demand" [2]*, M. Adelman and H. Jacoby, "Oil Prices, Gaps, and Economic Growth" [26], H. Jacoby, "MIT World Oil Project" [11], and H. Jacoby and J. Paddock, "World Economic Growth and OPEC Oil" [43]. The paper by Jacoby and Paddock is currently in draft form and will be completed in the Spring of 1981. Another four papers use simulation results from the demand analysis alone. They are: R. Pindyck. "Energy Demand and Energy Policy: What Have We Learned" [16], R. Pindyck, "The Characteristics of the Demand for Energy" [22], M. Adelman, Energy/Income Coefficients: Their Use and Abuse" [3], and "Energy Policy and the Oil Problem: A Review of current Issues," by Jacoby, et al. [36].

Four papers are based primarily on the supply analysis. They are: H. Jacoby and J. Paddock, "Supply Instability and Oil Market Behavior" [13], H. Jacoby, "The Oil Price 'Ratchet' and U.S. Energy Policy" [12], M. Adelman, "Constraints on the World Oil Monopoly Price [1], and M. Adelman, "The Clumsy Cartel" [4].

Calculations Performed for Others

We have received requests to use our World Oil Model for simulations of oil market responses to various assumed scenarios. Generally these calculations have been policy-analytic in nature; others were tests of the sensitivity of our model to another model's data base. The following is a list of simulation runs performed in response to these requests:

1. U.S. Department of Energy, International Market Analysis Division. DOE supplied us with various scenarios on price, GNP growth, and Saudi Arabian capacity which they were using to aid in U.S. energy policy formulation. We made several model simulations based on the scenarios and provided the results to DOE along with our analysis of their scenario assumptions.

2. U.S. Department of Energy, International Affairs Division. This Division requested simulations of our model based on "standard" scenarios. Our results were to be incorporated in a DOE publication which compared the simulation results of several energy models. An internal DOE memorandum describing our results was then to be used by the Secretary's office in formulating U.S. energy policy.

3. Energy Modeling Forum, Kennedy School of Government, Harvard University. EMF Study #4 requested results from our demand model for discussions on price elasticities.

4. Energy Modeling Forum, Stanford University. We are cooperating with the EMF Study #5 on U.S. Oil and Gas Supply Models. We will be simulating "standardized" scenarios to be used for comparison purposes with other models. The objective of the Study is to better equip U.S. energy policy analysts with a knowledge of the key assumptions and meaningful results of these models.

5. National Petroleum Council Study on U.S. Refinery Flexibility. We cooperated with this study by providing our simulations of world oil productive capacity and demand. The Study's objective is to analyze present and future U.S. refining potential, by product.

6. U.S. Department of Energy. The Energy Information Administration requested simulations of our model based on "standard" GNP growth and oil price scenarios. These results will be pulished in their Annual Report to Congress, which will contain a comparative presentation of the results of other international oil models.

7. Energy Modeling Forum, Stanford University. We are involved in EMF Study #6 on international oil and gas supply models. As in

EMF Study #5, "Standardized" scenarios will be simulated by several different models. The results will be compared so as to better inform model users of the strengths and weaknesses of these models for policy-analytic purposes.

Conferences on the World Oil Market

In October 1978, April 1979, November 1979, and May 1980, the M.I.T. Center for Energy Policy Research sponsored meetings on the condition of the world oil markets. In November 1979, the Center ran a conference on Energy, Inflation and Economic Growth which included a session devoted to world oil developments. The basis of data and analysis, and conference organization and leadership were provided by Adelman, Jacoby, and Paddock, along with assistance from World Oil Project staff and students. All incremental costs associated with these Conferences were paid by the M.I.T. Center for Energy Policy Research, but the data and analysis that went into conference documents were a direct result of this NSF sponsored research. Appendix D contains the meeting schedules and lists of the participants for these Conferences.

Subtask 3.1.b Analysis of Producer Tax Systems

The North Sea has been the focal point of work on this subtask. In the North Sea, a tax and participation system (rather than a bidding system as in the U.S.) has been designed to capture the economic rent associated with oil and gas. The fiscal variables include royalty payments; petroleum revenue tax; corporate tax; and special deduction and depreciation rules such as the ring fence and uplift provision, oil allowance, and maximum liability provisions.

The ideal tax system removes economic rent only, and leaves investment unaffected at the margin. Actual tax regimes appear to depart substantially from the ideal, so it is necessary to examine each tax package to determine the extent of its neutrality. In the absence of a tax system, production and exploration decisions would be made on the basis of known economic factors, expected geologic discoveries, and future prices. A non-neutral tax could bias these decisions so that the most efficient solution would not be obtained.

A memorandum by H. Owsley, "The Effects of North Sea Tax Systems on Petroleum Reservoir Development" examines the theoretical bases for two alternative hypotheses (i.e., tax/no tax) and determines the optimal depletion rate under each scenario. These solutions are compared to actual results from Wood-Mackenzie data on the North Sea, showing the "neutrality loss" caused by the taxes. The analysis also examines alternative tax systems and evaluates their relative neutrality vis-a-vis a no-tax world. A related memorandum by I. Paddock, "Survey of North Sea Oil Development Financing" (see Task 3.3) describes the various tax systems and licensing arrangements used by the Norwegian and British governments.

Task 3.2 Further Developments of the Disaggregated Model

The work related to this task has drawn the greatest concentration of effort, and this area of research has been very productive. Although the original task plan called for three working papers; we have completed three and have four others in draft form. The three major areas of research covered by these papers are: (1) disaggregated analysis of discovery; (2) endogenous development drilling rates, and (3) drilling cost estimation and analysis.

Disaggregated Analysis of the Discovery Process

Our work on a disaggregated approach performed in the previous grant was outlined in a working paper by M. Adelman and H. Jacoby, "Alternative Methods of Oil Supply Forecasting" [5]. This paper was revised and published in the current grant period. A procedure for estimating the supply potential for a region involving analysis of finding development and production of reservoirs is described in P. Eckbo, "A Basin Development Model of Oil Supply" [10].

Under the current grant, our disaggregated analysis has focused on two major areas: discovery and development. The discovery analysis examines the statistical modeling possibilities for exploratory effort and return. Exploration in sedimentary basins results in new petroleum reservoirs; but the amount of new reserves is subject to great dispersion around the expected discovery-decline. Discovered reservoirs are available for development into proved reserves out of which oil production is possible. But some reservoirs are not worth developing. The development over time of an inventory of discovered reservoirs is subject to many factors of price and relative cost. To the maximum extent, we need to treat each field separately, unlike our earlier work which treated countries as homogenous units.

The objective of our research on disaggregated discovery is to determine how to estimate and, if possible, set limits on the sequence of petroleum resources yet to be discovered in a partly explored area. The approach pursued uses data on historical sequences of fields discovered and their estimated recoverable reserves, and numbers of exploration wells drilled. No use is made of geological data or judgment, except as a "censor," to rule out sequences which geologists would consider unlikely or logically wrong.

We have constructed four models for detailed study, representing a range of levels of complexity. The simplest model postulates only that discovery probabilities are proportional to field size, as indexed by millions of barrels of recoverable hydrocarbons. Greater sophistication is then added to obtain the other three models, by specifying a lognormal distribution of field size, a more general discovery probability law and a link between discovery rate and drilling activity.

The performance of these models is examined using data for the Northern North Sea (56-62° North) in "Probabilistic Methods for Estimating Undiscovered Petroleum Resources," by F. O'Carroll and J. Smith [14]. The main source of data is an amalgamation of five published compilations, and includes both oil and the oil equivalent of gas. An alternative data set, covering oil only, is based on ad hoc assessments by exploration personnel currently working in this area. Results from each model-fitting exercise include the estimated number of fields in each of seven broad size-classes and the implied total undiscovered resources. The uncertainty inherent in the estimation process can also be quantified. This is done by calculating error bounds for total resources which, if the model is correct, have roughly a 95% chance of covering the true value (95% fiducial limits).

In some respects, different models and data lead to similar conclusions for this North Sea Analysis. For example, all calculations agree that there are no more fields to be discovered in the two largest size-classes, and that there are few, if any, undiscovered fields with recoverable reserves of 500 million barrels or above. The models also agree that the majority of undiscovered fields are in the smallest class in the range considered.

With regard to the total volume of resources in undiscovered fields, however, different modeling approaches give widely different results. The estimated total of petroleum resources in the area ranges from about 2 to 17 barrels for the volume in undiscovered fields, depending on the model. This is similar to the range of estimates available from various oil industry sources in recent years, using geological data and judgmental methods. Even wider uncertainty surrounds the estimates of total resources which is of the same order of magnitude as the estimate itself. A discussion of these results is presented in "A Probabilistic Model of Oil Discovery," by J. Smith [24].

The main lesson of these alternative modeling strategies is that better results may be obtained with relatively simple discovery models. More ambitious models attempt to improve precision by representing the underlying processes in greater detail. But errors in such models appear to be magnified in the estimates. The net result is to significantly degrade rather than improve the quality of the estimates. In our analysis there is evidence of adverse effects of this kind due to three features of the more sophisticated models. These features are: (1) the assumed lognormal distribution of field sizes, (2) the generalization of the finding probability law, and (3) the attempted linking of discovery

rates with exploratory drilling activity. While these features are generally considered robust, our results cast doubts on this view. We now believe that until these 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. An extension of these results is presented in "Maximum Likelihood Estimates of the Size Distribution of North Sea Oil Deposits," by J. Smith and G. Ward [46].

Our empirical work on disaggregated development analysis by field has focused on Egypt and Mexico. The analysis is being carried out in stages, each part being modular in the sense that it can be altered or improved without changing the structure of the model itself. The core is a straightforward flow-rate depletion method; feeding it are the projections of extension drilling (in rig-months) and number of wells. The model gives a smooth and "believable" representation of the expected production pattern of fields already in use. The output will be used to supplement or modify existing supply-side forecasts of production in the larger World Oil Project model. The results of this work are contained in a set of internal research memoranda by H. Owsley and in a forthcoming paper by M. Adelman and H. Owsley, "Forecast of Crude Oil Production Capacity for Mexico" [39]. The results for Mexico will appear in working paper form at a later date under our continuation funding grant.

Development Drilling Rates Given Discovered Reserves

We have carried out theoretical work on endogenizing the field development path and drilling rate in our supply analysis. The results of this analysis are presented in forthcoming working papers (now in draft) by J. Paddock, "Investment Theory and the Development of Exhaustible Resources" [44], and "Endogenous Development of Drilling

Rates in Petroleum Supply: An Empirical Analysis" by M. Adelman and J. Paddock [38]. The basic hypothesis of that research is that production possibilities from discovered reserves of natural resources are determined by two key, interrelated factors: (1) the rate of investment which develops probable reserves into proved reserves; and (2) the rate of extraction from those proved reserves. Both these factors are intertemporal choice variables of the resource owner.

Analysis of optimal extraction paths for resources received considerable attention both in our earlier work and that of other researchers. R. Pindyck, "Optimal Exploration and Production of a Non-Renewable Resource" [15] was a working paper under our earlier grant and has now been revised and published. However, these earlier studies did not explicitly examine the concomitant decision on investment in productive capacity, which is a second control variable and indeed can affect the extraction cost pattern. Investment to develop proved reserves may, for example, be subject to economies of scale such that a dynamic marginal cost analysis will dictate installation of excess capacity in earlier years. Our objective in the paper on investment theory for exhaustible resources is to analyze the investment decision and its simultaneous relation to the extraction path for a price-taking developer.

Using an optimization methodology, we obtain solution paths for the two control variables (the rates of investment and extraction) which maximize the net present value of the resource. Two key innovations in this model are contained in the cost structure. First is the concept of "adjustment costs" which are incurred when the developer adjusts his capital base, e.g., his drilling capacity. These costs can be of two

types: (1) those which are internal to the project; and, (2) those which are due to imperfections in the factor market. If these frictional costs rise more than proportionately with increases in the relative rate of investment, then the optimal investment program is shown to be a distributed lead over future time periods. If one neglects these costs, and assumes that capital stock can be adjusted instantaneously, then the developer behaves in a myopic fashion.

Second, the relative rate of depletion of a given reserve likewise has costs associated with its intertemporal adjustment. Rates of production greater than the optimal withdrawal rate incur these additional costs in the form of losses of proved reserves; these losses come from several sources, and are a function of the characteristics of the reservoir.

Solving this dynamic model yields several other interesting results. We find that the rate of investment and reserve development, and the rate of production out of those proved reserves, are strictly lower than earlier research indicated for any given price and cost structure. However, we do find that our non-myopic developer may, under certain circumstances, build up excess capacity in both state variables: his drilling capacity and his proved reserves. We are able to analyze this behavior by decomposing the investment opportunity set into those factors which affect it as a result of the developer's choices, and those exogenous factors which affect shifts in the set itself. We then perform a preliminary comparative dynamics analysis of different time paths of investment and production with respect to changes in key parameters, in particular the interest rate and oil price.

Finally, we analyze a numerical approximation to a solution. From this, empirically estimable equations are specified. These hypotheses will be tested in later research under the continuation grant funding.

Drilling Cost

To support the larger task of disaggregated model development described above, we have initiated a drilling cost and investment analysis for both offshore and worldwide areas. Analysis of offshore cost is found in P. Eckbo, "Estimating Offshore Exploration, Development and Production Costs" [41]. The results of our worldwide analysis are contained in "Estimation of Worldwide Production Costs for Oil and Gas," by M. Adelman and G. Ward [6]. the purpose of this cost study is first to develop the relationship between U.S. oil and gas costs and their determinants, and then apply it to other areas in the world.

The analysis has focused on rig time as the principal determinant of long-run marginal cost. Rig time is of course correlated with depth drilled (the more usual proxy), but it also captures the composition of the crust drilled through--e.g., it takes longer to drill through a foot of rock than a foot of sand.

On and offshore operations were segregated because fundamental structural differences between the two are so great that pooling of observations is not appropriate. Water depth can be reckoned as an important determinant of cost, as can distance from shore. Data were obtained from the API's Joint Association survey of the U.S. oil and gas industry and the Hughes Tool Company, supplemented by trade journal material. Results suggested that cost relationships are fairly stable and reliable when applied to onshore wells, but that better cost breakdowns are necessary if offshore areas are to be forecast with any confidence.

The analysis of resource production through the use of cost curves, and the application of results to explain firm and industry output, is further explored in "Production of Depleting Resources: A Cost Curve Approach" by P. Bradley [28].

New Integrated Supply Model

These efforts on discovery, development and cost were combined into a preliminary version of a disaggregated supply model. The results are contained in a draft working paper entitled, "Regional Modeling of Oil Discovery and Production" by J. Smith [45], which presents a new method for summarizing the exploratory and production potential of a geographical region in terms of the past history of exploration and production of individual fields. We link the discovery and development models through the variables: size of marginal discovered field and development investment requirements. First, the discovery analysis estimates the size of the next field to be discovered in the area by exploratory drilling. This marginal field size is the addition to the potential reserve base. Given size and the other parameters, we estimate the costs of bringing the marginal field(s) on stream, and also describe the likely production rate from fields of distinct physical characteristics. The output of the two stages is an approximate forecast of the reserve additions and future production that are likely to arise from specified drilling programs.

In both the exploratory stage and the production stage, the negative influence of resource depletion is modeled explicitly. The expected size of successive field discoveries is subject to exponential decay at a rate determined by analysis of past discovery history. The exponential discovery decline is a simplified but adequate form of the type of

discovery behavior exhibited by the earlier disaggregated discovery models of Kaufman and Barouch. When a given field enters the production stage, the flow declines exponentially from the peak rate as the field is exhausted. This production process is a generalized form of the model applied to aggregated regions by Adelman and Paddock [27].

Finally, we introduce some new development cost functions that are sensitive to both economic parameters and the physical characteristics of fields. The cost functions relate total investment expenditure to the size of the field, the rate of extraction, and the productivity of individual wells. As expected, the estimated cost functions display considerable economies of production from individual wells, lesser economies with respect to total field size (in onshore regions), and strong diseconomies to accelerated extraction rates.

The analytical framework is empirically illustrated by application to twenty-five individual regions (including both offshore and onshore) around the world.

Task 3.3 Incorporation of the Influence of Financial Factors on Supply

Two areas of research were pursued under this task: (1) macrofinancial influences on oil exporter behavior; and (2) the effect of financial institutions and instruments on oil investment and production.

Macrofinancial Influences

Internal financial decisions of oil-exporting countries may have important effects on the determination of how much oil those countries wish to supply. These relationships between the financial and real sectors are not well understood. They compose a series of economic trade-offs over time. The country must choose a method of "paying" for a desired path of economic development and consumption. It must choose a combination of (1) oil reserve development and production (for both domestic use and export revenues) and (2) foreign borrowing or lending. For example, the country may borrow heavily today in international financial markets, meet debt service out of the increasing oil revenues, and later repay the debt and build up a stock of foreign financial assets.

At the time this M.I.T. project began, investment and production decisions in world oil were still being made by private companies, subject of course to taxation and ultimate control by governments. But the evolution of the last six years, accelerated this past year and a half, has put the governments in complete direction of the process, with the companies as producing contractors or expert advisers; in some countries (Kuwait, Venezuela), the companies have even relinquished the advisory role, and left the scene completely.

Thus for the great bulk of the oil moving in export markets, the investment-production decisions are now the subject of a political process, made by a sovereign government. It is not obvious that public

decisions need be substantially different from private, nor that objective functions differ. The more wealth a government can draw from oil operations, the better it can accomplish its political goals, such as domestic peace or foreign policy objectives. But it does not follow that the political process must result in substantially the same result; in many instances the results do appear to be substantially and persistenty different. We try to discover those factors which would control a government investment decision.

Figure 1 shows the set of factors involved, viewed simply from the standpoint of money flows and their effect on domestic affairs. The arrows show the direction of payments and receipts. From the viewpoint of the government, spending on oil exploration and development competes both with other assets (such as financial holdings abroad and real assets at home), and also competes with consumption. To subordinate investment to consumption implies a relatively short time horizon; yet this seems to be characteristic of Venezuela, Mexico, and Indonesia, for example, where the large-volume sale at home of oil at very low prices, and at a very high opportunity cost, again shows the importance of consumption as perceived by the state.

Furthermore, the whole structure of money flow is joined with the national budget, the national income accounts, total GDP and the price level, so that investment decisions may be aimed not merely at equating the incremental rate of return on the three types of assets, but on how much price inflation is likely to result from one or another kind of spending and receiving. We have completed work on several areas related to the influence of financial forces on oil supply. A beginning of this work is contained in M. Dailami, "The Determination and Control of Money

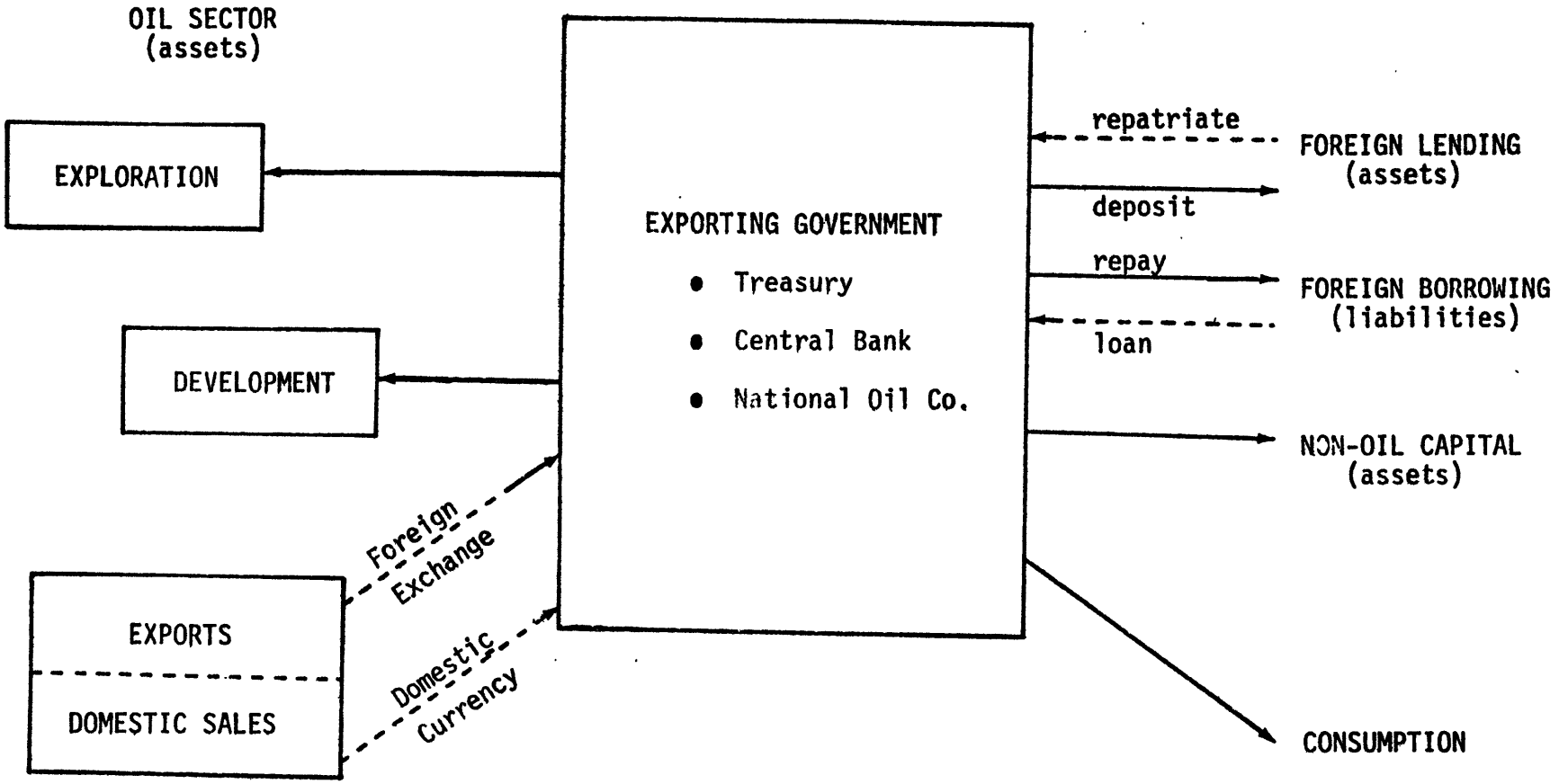

FIGURE 1. EXPORTING COUNTRY FINANCIAL FLOWS

Payments ——→

Receipts - - - - - →

Supply in an Oil-Exporting Country: The Iranian Experience" [33].* This work analyzes the effects of oil revenues on the money supply and economy of an oil exporter. A later, related piece of research analyzed the purchasing power of oil revenues in terms of the oil-exporting countries' basket of imported goods. The results of this work are in M. Dailami, "Measuring the Purchasing Power of Major Currencies from OPEC's Viewpoint" [32].*

Much of our past work on supply has been based on functional relationships among petroleum reserves, investment, costs, and prices. We have moved from a simple inertial model toward the incorporation of disaggregated price, reserve, and cost data. However, even the best of such models may be incomplete. The behavior observed in many key price-takers (as well as price-makers) seems to be influenced by considerations of "finance" in a broad sense. Both oil sector investment expenditures and perceived oil revenue "needs" affect supply decisions. Expenditures made now to increase the stock of proved reserves are a drain on current investment, but will provide a flow of revenue later. Hence oil production investment is part of a larger whole. Moreover, the balance of payments effect may be, at first, negative, then positive. If balance of payments objectives or constraints are an overriding priority, they will influence oil production capacity determination. Thus, the neoclassical analysis alone cannot explain investment and production decisions which we observe. Financial factors may work with or against

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*The work of M. Dailami [9,31,32,33] was supported in part by the MIT Center for Energy Policy Research. Some papers [31,33] reflect research that was begun before Dr. Dailami joined this project. The existing NSF-sponsored work on finance, and some direct financial support, made it possible to complete this research and extend it into related World Oil Project research areas.

others. This interplay must be incorporated into our oil production model.

As a first step towards that objective, we have devised a rudimentary macrofinancial model which describes the effects of oil revenues on the financial and macroeconomic conditions in the exporting country. Our NSF grant did not provide for the actual empirical estimation of such a model, nor have project resources been sufficient to the task. Fortunately, however, this activity was of interest to the U.S. Department of Energy. A separate contract with DOE was written to apply the country-analysis methods (which had been developed largely with NSF support) to two specific countries of interest to the DOE, Venezuela and Mexico. The Venezuela model is described in a working paper by M. Dailami, "Financial Influences on the Behavior of Oil Exporters" [9]. The Mexico model is described in a draft paper by M. Dailami, "A Macroeconomic Model of Mexican Oil Supply" [42].

As applied to these two countries, the models are essentially open-economy Keynesian frameworks which include equation systems for the external sector, the domestic monetary system, and the government sector. The Venezuela model contains fourteen equations determining the government's budget (expenditures, revenues, and financing options), private expenditures, the balance of payments position, the monetary base, and GDP. All variables are in nominal terms. The model can be used to analyze the impact of changes in oil revenues on the domestic economy. Given an anticipated oil revenue trajectory, the model computes the resultant GDP, money supply, government deficit, government foreign debt position, and level of international reserves, as well as other macroeconomic variables.

Alternatively, the model determines the net oil revenues needed for sustaining a given economic growth target. If the country is a price-taker, any given amount of revenue implies a certain level of production and a certain level of expenditures on investment and operating cost. This production target and its investment requirements must be fed into the production model to see whether the results of the two models are consistent. To meet the supply and revenue targets, additional capacity may be needed, and hence additional investment. The country must finance any given desired path of investment and consumption from oil revenues and foreign borrowing. A major complication is in the treatment of oil-derived investment, i.e. refining and petrochemicals. These are extremely capital-intensive. They need not be, but usually are, treated as though they were a necessary complement to oil production. The net effect on the financial model is to increase the required spending on the oil option, and decrease the return. The cost and nature of the foreign borrowing alternative are currently treated in a very simple fashion. (The interest premium over LIBOR is constant, and no debt capacity constraint is specified.)

The model for Mexico is more complex than that for Venezuela. Oil is a much smaller (though growing) proportion of the economy. As a result, other sectors contribute more significantly to GDP. In addition, Mexico's non-oil export base is much broader, because Mexico has advanced well beyond protected import-substitution industries. Also, the government's budgetary position is more complex, as non-oil revenues--mainly taxes--provide the bulk of total government revenue. Thus, our macrofinancial model of Mexico contains a more elaborate treatment of both non-oil exports and other government revenues in its simultaneous

equation system. This system also includes an accelerator-type aggregate production function and a simple price equation. Whereas the Venezuelan model is currently all in nominal terms, we have done some preliminary investigation of inflation in Mexico.

These two empirical applications have provided useful insights into the oil supply decisions of two countries, and the effect of export revenues on their domestic economies. These two cases now form a useful base on which to build further research on the methodology for analyzing the interaction of macrofinancial and microeconomic influences on oil supply.

Financial Institutions and Instruments

International financial markets and institutions have played an important role adjunct to oil markets. We have performed an examination of the economic measures that the IMF includes in its stabilization programs, as a condition for loans to developing countries. The result of this work is contained in a memorandum by J. Humber, "IMF Funding." We have also examined other existing major world oil supply models and the consideration, if any, that these models give to the impact that financial factors have on the supply of oil. The major findings, although limited, are contained in a memorandum by J. Humber, "Financial Factors in Oil Supply Models."

On another aspect of the financing problem, we are experimenting with the use of the Capital Asset Pricing Model to study the cost of financing for development investment in the North Sea. The focus of this research is on the private financial markets. It is hoped that results will be transferrable to other areas of the world, and that they can be incorporated in the Disaggregated Model of Oil Supply discussed under

Task 3.2 above. As background for this work, a detailed history of North Sea finance--both the U.K. and Norwegian sectors--has been prepared in a memorandum by I. Paddock, "Survey of North Sea Oil Development Financing."

The linkages between world energy and financial markets, such as the role of international financial markets in the adjustment of the real markets for energy, are explored in T. Agmon, D. Lessard, and J. Paddock, "Financial Markets and the Adjustment to Higher Oil Prices" [7]. This working paper was revised and published under the current grant. Out of that work has come a draft of a paper which explores the impact of financial factors on price-taker supply. This paper is "Financing Petroleum Development in Developing Countries," by T. Agmon, D. Lessard, and J. Paddock [40]. This paper discusses why international finance is fast becoming a key element in the analysis of international energy markets and policy. Financial considerations may have important impacts on energy-related decisions of both importers and exporters, and developments in energy markets are likely to have important feedbacks to financial markets. While the relevance of finance to policy is clear, the research which has been conducted to date has only scratched the surface.

In this paper a key question is addressed:

> What is the impact of international financing arrangements on the capacity and production decisions of price-taker oil-exporting developing countries, and can more appropriate financial institutions and mechanisms be adopted?

To answer this question, one must examine the impact of oil price uncertainty on the development plans of price-taker developing countries that require external financing for oil development (and oil-wealth-induced consumption). It appears that the structure of international

financial institutions and instruments can influence the path such a country will take.

Most current investment relies primarily on credit from commercial banks or equity investment by integrated oil companies. In the absence of changes in this system developing countries with financial deficits but substantial energy potential may be overly constrained in their development plans by a desire to avoid large fixed external financial claims by borrowing against uncertain future revenues. Or those countries may take on undue risks and encounter financial difficulties that may threaten their development plans as well as the stability of the international financial system.

Although oil-endowed countries have experienced an immense increase in their wealth in recent years, they have experienced an accompanying increase in the uncertainty of their income stream, especially if measured in terms of the real goods which it will purchase on world markets. Since in most cases, producer countries depend for an inordinate share of their external receipts on oil, this uncertainty regarding the "terms of trade" of oil over time will have an impact on the rate at which specific countries develop their reserves. Alleviation of this uncertainty is particularly crucial in price-taker countries for which oil comprises a substantial portion of their national wealth and export revenues.

There are several alternative ways to reduce the apparent variability of the terms of trade of oil facing these countries. These alternatives give the first set of conditions under which those producers would be willing, other things remaining equal, to increase the rate at which they develop reserves and produce oil. Innovations in

international financial institutions and instruments which could reduce the reluctance of those countries to develop their oil reserves at a more rapid rate are identified in this paper; they include the World Bank Exploration Fund and Mexico's Petrobonds, among others.

One interesting program proposed to fill the needs outlined above is an oil development fund. This fund essentially would function as a financial intermediary, and be subscribed to by the major consuming countries so as to finance oil development by commodity-linked instruments.

Task 4.1 Analysis of Internal Cartel Allocation

The developments of the past two years in the oil markets have, in our opinion, confirmed our avoidance of any optimizing or uniquely determined model result. Instead, we have favored a disequilibrium model where the price was evolving toward a neighborhood of revenue-maximizing price-output conditions. It is like modeling a westward movement from Boston toward a point which may be as close as California or as far as China. We do not know where the point is, and the odds are good that even in retrospect it will be unknown because the feedback or cybernetic mechanism which guides the vehicle is slow and distorted. In international energy markets, the demand response is strong but operates with long time lags; while the supply response probably cannot be captured by econometric techniques even under competitive conditions.

Our demand model is passsive, in the sense that we have quantities determined in lagged response to price changes of earlier years. It is not apparent that demand has moved into the elastic range, hence it was not (and is not) unrealistic to assume an autonomous rising price, not determined by supply-demand interactions.

On the supply side, our first estimates of development cost (Adelman and Ward [6]) have been completed. Another paper in process (Smith [45]) demonstrates that the country-by-country cost estimation results are well described by an equation based on average field size, intensity of exploitation, and flow rate per well. It follows that in the cartel core marginal cost is so small a fraction of price that there is no cost barrier to output expansion. Hence the price of oil is not yet determined by demand, nor supply.

The simulation process of our model is one of gradually rising world

productive capacity outside the cartel, as potential reserves slowly became probable reserves and then proved (developed) reserves. Demand on the cartel was (and is) a residual quantity, which has been practically horizontal since 1973. The simulation is gradual and smooth. Shocks are always possible and even likely, but we have not endogenized those shocks, and have no intention of doing so.

Nominal prices did in fact increase periodically during 1974-78, but the worldwide inflation and dollar devaluation caught up periodically, making the real change roughly zero. This is turn engendered disappointment and irritation among cartel members, who felt entitled to the higher prices, and more, felt cheated by having their gains annulled during the course of time.

There were signs in 1978 of a turn toward direct control of the volume of output. Changes in the market as a result of increased nationalization of oil is explored in "The Effect of Increased National Oil Company Sales on OPEC and the Long Run Structure of the International Oil Market" by H. Owsley [37]. This took the form of controlling the proportion of light to heavy crude oils by several countries, most notably Saudi Arabia. But no measures were taken to adjust prices to any new output pattern, nor to permit prices to adjust freely. This made the situation unstable. There are a number of variables so interrelated that a change in one becomes a disturbance to the others. These were (1) relative crude values, derived from product prices, and (2) relative crude prices, which were set with only an imperfect relation with (1). Because of frequent changes in (1), even a "correct" structure in (2) was frequently disturbed. But changes in the difference between (1) and (2) had also a direct effect on: (3) multinational oil company realizations,

and on: (4) market shares of the producing countries. In short, whatever the formal or informal allocation mechanism, demand and price changes were an unavoidable disturbance to it.

As had been repeatedly demonstrated, changes in relative values of crude oil, not matched by changes in prices, caused a non-negligible change in oil company purchases, a switch from less to more favorable suppliers. There had been sericus though not prolonged embarrassment for Abu Dhabi in 1975, then a much more serious situation for Nigeria in 1977-78, when it lost considerable revenues to Libya and Algeria, who were more ready to make small price reductions.

Thus the allocative mechanism of the cartel was under strain by early 1978 because of the particular situation in Nigeria, and because the chronic oversupply of crude oil had made it difficult to increase prices. There was therefore chronic talk of some kind of mechanism for collective decision-making on production control, which necessarily implied allocation, which Saudi Arabia openly opposed, and whose difficulties others could see.

One cannot tell how long this state of affairs would have continued. It was quickly changed by the Iranian revolution, and the swift downturn in Iranian exports to a temporary bottom of zero in January 1979, whence it recovered quickly but only partially.

There was no unitary response to the suddenly acute problem of total non-Iran production, and its allocation. Outside the Persian Gulf, the response was simple: short-term capacity was fully utilized. This seems to have been true even in Venezuela, where it has steadily decreased since 1973, to the point where some fairly strenuous efforts are now being started to increase it.

Thus the collective decision, such as it was devolved upon the Persian Gulf producers. At a fairly early stage in the crisis, November 1978, Kuwait and Abu Dhabi declared they would not increase output. However, their deeds appear to have been less intransigent than their words, which expressed total indifference both to total output and to its allocation. Neither Iraq nor Saudi Arabia made any commitments, but they watched Iran with probably as much uncertainty as the rest of the world. Sheik Yamani on one or two occasions expressed his confidence that Iran would soon be back in the market--not indeed to the level of the first half of 1978, but above that of late 1978, and a fortiori of early 1979.

It seems like a reasonable presumption that none of the Persian Gulf producers wanted to produce a panic on the oil market. They doubtless had an aversion both to acute shortage and to glut, but not an equal aversion. The problems of too little oil and upward price pressure are more bearable to the seller than of too few buyers and unpleasant jostling with one's rivals. Thus the choice of the big four Persian Gulf producers was a biased choice, as every participant had to know.

Any group which tries to keep any market in balance is in constant danger of taking steps which are just right for past conditions, wrong for today. A government balances inflation and recession--by slamming on the brakes just when the economy is grinding down. Similarly in the oil market. Saudi Arabia had increased output past its proclaimed ceiling of 8.5 MBD to 10.5 in December and January. But late in January, in response to what they doubtless thought to be signals of speedy Iranian resumption, this amount was abruptly cut to 8 MBD, in order to keep production for the whole month stepped down to 9.5 MBD. It stayed at 9.5 for three months then was further reduced to 8.5 for three months.

Starting July it was again raised to 9.5 MBD, where it has stayed since.

But by late January, the situation of only mild shortage and gradually rising prices was untenable. The result, not of any formal decisions but of a sequence of actions and non-actions, was that the Persian Gulf producers were no longer fixing a price and letting output adjust. All of them were now trying to observe some kind of pre-determined production schedule, which except by improbable chance had to be too much or too little, either more or less than was demanded at that price. If too much, the odds were good that production would be cut back. If too little, there was no assurance of anything. Thus buyers and sellers knew a shortage was much more likely than a glut. The producers had, in effect, slipped back into the situation in late 1973, where output was expected to be less than demanded. The reaction was the same.

The short-term oil market is very unstable because oil is a perishable product with relatively small stocks relative to current consumption. (In contrast, the economy can easily adapt to total cessation of a durable good--e.g., automobiles after December 7, 1941.) The value of a barrel of oil is measured by the damage done by not having it; and this "consumer surplus" is usually many times the price, however high. Hence the fear of death sets off a panicky scramble for supply for final users, refiners, and middlemen.

In retrospect, it is difficult to say whether there ever was any shortfall in supply. Total Iranian exports have been 5 MBD, or 10 percent of world non-Communist consumption. For the six months from October 1, 1978 to April 1, 1979--when Saudi Arabia cut output back to 8.5 MBD--Iran exports averaged about 2-1/2 MBD, a fifty percent loss

which could have been and very likely was made good by expanded production elsewhere. But the small expected shortfall generated an abrupt surge in demand for hoarding, not consumption. Had the Persian Gulf producers said that they would meet whatever demand they found, they would have taken the edge off the panic. But this they would not do. Their March meeting, where Sheik Yamani reproached the Iraqis for producing too much and concealing it, showed their ordering of priorities--first avoid the glut, then try to moderate the famine.

The full force of the excess demand was channeled into the spot market, which then accounted, very roughly, for some 15 percent of total crude oil traded. Thus whatever the price impact would have been if all oil had been sold currently, was multiplied by a factor of about seven. The spot prices climbed far over the contract prices or Government official prices at which most oil was moving, and just as in 1973, it soon began to drag up the list prices. Fringe benefits and premiums were added, then official prices were raised, but at all times they lagged behind spot prices. The temptation was great, and not long resisted, to reduce sales to regular customers, the multinational oil companies, in order to sell at spot to other companies, or to independent refiners, or to brokers, or to make government-to-government deals, or do whatever ingenuity could devise and sore need would tolerate. But in a rather short time, the multinational oil companies lost their usual supply of crude which they had formerly resold to those same third parties to whom the governments were now selling directly. This diversion was sometimes increased by more direct action, as when Nigeria expropriated BP on the rather lame excuse that they were doing business with South Africa (as was Nigeria, for that matter).

Thus by mid-1979 there had emerged the three leading aspects of the change: (1) direct production control by the Persian Gulf producers, which made the market unstable and produced a kind of permanent shortage. (2) Production exceeded consumption persistently, but the additions to inventory made demand exceed supply. (3) The bypassing of the multinational companies. The pattern of refining and marketing was little affected; the old multinationals held their market shares at the consumer end; but they no longer held the interim terrain, and it was hard indeed to know where crude oil and products were going, through what channels, before it ended up in the same places for final sale to consumers. But the old supply networks and routines had been thoroughly disrupted.

For the year 1979, additions to inventories averaged about 1.5 MBD, about 3 percent of current consumption. During the first half of 1980, spot and contract prices gradually and gingerly converged. Consumption decreased, partly because of general shock, partly in response to higher prices, partly because of industry slowdown and U.S. recession. Contract prices continued upward to close the gap with spot prices. Lower demand led simply to production cutbacks. While demand exceeded supply, the allocation problem again came to the surface. It was complicated by the disorder in prices. Since Saudi Arabia persistently lagged the others in raising contract prices (although it generally made increases retroactive) it could sell all it could produce, and hence bore none of the brunt of the cutbacks. The situation was generally regarded as unstable, right down through the OPEC meeting of June 1980, which raised prices again, with the Saudi response expected as a catching-up by September.

The participants on the project indicated their first reactions to the new market conditions and reported some of the above analysis in papers given in June 1979 (Adelman [25], and Jacoby and Paddock [13]). A later version was given in December 1979 (Adelman [4]). The situation is still too fluid for any definitive statement even of what happened, but perhaps the foregoing sketch will make it clear why there is no expectation among the investigators to make any change in the model. Price changes will still drive total consumption, but if the cartel core insists on staying with direct production control, the path will be much more disturbed than was expected two years ago.

Task 4.2 Analytic Models of Cartel Behavior

Our earlier work on cartel behavior included the development of analytical models which were used to calculate optimal pricing policies over the next 20 or 30 years under a set of simple assumptions about the structure of the world oil market. More recently we have also been using our optimizing framework as a means of looking at some other issues in OPEC pricing policy. In particular, we have been concerned with the extent to which a growing burden of production cutbacks on a small core of countries might ultimately reduce the monopoly power of the cartel. (In the short term at least, this is less of an issue because of the Iranian disruption.) We have approached this issue by running our monopolistic optimal pricing model under assumptions that certain cartel countries produce at full capacity over the next 20 years. Similarly, we have applied the optimization framework to the analysis of the effects of an increase in Mexican oil production on the cartel price. By running the model under the exogenous assumption of Mexican production growing to 7 million barrels per day by 1985, we have calculated the impact on the cartel price on certain assumptions. We found that the impact is not very large. In particular, the price of oil in 1985 would only be about 10% lower than it would be otherwise with Mexico on stream. These results are described in the working paper by R. Pindyck, "Some Long-Term Problems in OPEC Oil Pricing" [21]. Also, some of this work was reported in a newspaper article by R. Pindyck, "OPEC's Dilemma: How to Control Production Levels" [17].

We have also looked at the issue of the cartelization of world commodity markets in a broader context, going beyond oil. A question that is of considerable importance today is whether there are likely to

be many "OPECs" in the future, i.e., are the markets for other commodities likely to become cartelized? Our preliminary answer to this questin is "no," and the reasons behind this answer are spelled out in the paper by R.S. Pindyck [19].

Task 7.1 Portfolio and Supply Decisions by OPEC Countries

In modeling the behavior of oil-exporting countries one may view oil policy as an asset management problem. The behavior of these countries has become an increasingly deliberate exercise in portfolio selection under various constraints. To meet its economic development objectives, the oil-producing country must allocate its portfolio among the following assets: (1) oil in the ground, (2) internal investment, and (3) external financial assets, to be drawn against later for future expenditures. Analysis of the effect on supply of this portfolio allocation will be dependent on five parameters: (1) average vs. marginal development cost of oil; (2) capital requirements for oil development; (3) anticipated prices, and output levels tolerable to other cartel countries, with their inherent aspects of uncertainty, including demand levels and cartel cohesiveness; (4) domestic rates of return and the associated risk; and (5) the risk-return characteristics of external investment opportunities. Both (1) and (2) are powerfully affected by the production/reserves ratio. To state the polar extremes: Case A, a low ratio implies a flat marginal cost curve and a very low present value of the distant marginal barrel; Case B, a higher ratio implies high values both of marginal cost and present discounted value.

The Case B countries are the high-absorbers, typically in deficit on foreign exchange account. Because of their internal development plans and their commitment to imports, their government revenues run short of expenditures, and export earnings are below imports. Thus, their problem is to decide whether to finance their expenditures by seeking higher oil revenues from increased production or by borrowing from abroad. The option of external financing is very attractive to these countries in

view of their low risk and high credit-worthiness. Several OPEC countries have issued bonds at very low spreads over the London inter-bank borrowing rate (LIBOR). An excellent case in point is Mexico, which has borrowed heavily to finance current expenditures, with the anticipation of higher future oil revenues to pay down their debt.

On the other hand the option of increasing oil revenues has to be considered within the limits set by the oil-production capacity of the country. Factors influencing these limits include the availability of oil reserves, average and marginal development cost of oil, and the allocation of a government's investments to the oil industry. The amount of the government's investment going to the development of oil production capacity is a crucial variable which would link our analysis of financial considerations to an analytical model of oil supply. The methodology for linking these two types of models will be developed under the continuation grant funding. Some of the preliminary work on this linkage was discussed under Task 3.3 above.

Preliminary work in this area has yielded two complete working papers, and a draft of another is soon to be written. A paper by M. Dailami, "The Choice of an Optimal Currency for Denominating the Price of Oil" [31], discusses the portfolio aspects of currency denomination of oil revenues to the exporter. Aspects of this work have been published by Dailami in an article entitled, "Inflation, Dollar Depreciation, and OPEC's Purchasing Power" [8].

Much of the work discussed above under Task 3.3 is closely related to the continuing work of this Task.

3. DISSEMINATION OF RESULTS

We have been involved in various actvities that were included in the utilization plan of our proposal. The publication of research results during the past two years of the current grant is shown in the first two sections of Appendix A; these two sections are entitled "Publications" and "Working Papers" respectively. Research in process which will be completed under the continuation grant funding is listed in Appendix A under the title "Drafts in Process." Appendix B presents all of the publications resulting from this NSF project since its inception in 1975. Appendix C presents a list of testimony, speeches, and presentations by members of the Project over the period July 1978 through June 1980 (along with some items from the weeks immediate preceding the start date of this grant, and which were not previously reported to NSF). Finally, the transfer of models, data bases, and results is discussed in Subtask 1.1.c above. The use of analyses involving our models' simulations and databases is listed in Task 1.3 above.

In addition, the MIT Center for Energy Policy Research sponsored four meetings on the world oil situation in October 1978, April 1979, November 1979, and May 1980. The basis of data and analysis, and the organization and leadership of these conferences were provided by Adelman, Jacoby, and Paddock along with assistance from Project staff and students. All costs associated with the Conferences themselves were paid by the MIT Center for Energy Policy Research, a privately-funded entity of the M.I.T. Energy Laboratory. These meetings have provided us with extensive contact with a set of outside experts; and therefore we have substituted these activities for the Advisory Committee anticipated in the proposed Organization and Management Plan. Appendix D contains the schedules of these meetings and the lists of the particpants for these conferences.

All other instances where data and models have been disseminated to others are catalogued above under Task 1.3 and Subtask 1.1c.

APPENDIX A

Cartel Behavior and Exhaustible Resource Supply:
A Case Study of the World Oil Market
NSF Grant No. DAR78-19044

Publications, Working Papers, Drafts in Process
For Period of July 1, 1978 through June 30, 1980.

PUBLICATIONS

1. Adelman, M.A., "Constraints on the World Oil Monopoly Price," Resources and Energy, September 1978. A summary appears in Petroleum Economist, September 1977. Originally released as Working Paper MIT-EL 77-038WP, "Producers, Consumers, and Multinationals: Problems in Analyzing a Non-Competitive Market."

   The consuming nations have the power to damage or wreck the world oil monopoly, but 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 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 while 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 objectives and can be neglected.

2. Adelman, M.A., "World Supply and Demand", presented to the Canadian Society of Petroleum Geologists in Calgary, 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; effects of crude oil price changes on the world economy and on consumer policies.

   Some preliminary results of M.I.T. the M.I.T. World Oil Project are summarized:

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 1980's, unless the monopoly is destroyed;

4) great uncertainty must itself be factored into the policies of business and government.

3. Adelman, M.A., "Energy-Income Coefficients: Their Use and Abuse", in Energy Economics, January 1980. Originally distributed as Working Paper MIT-EL 79-024WP.

The right way to estimate and forecast energy 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 are: the consumption-income relationship, the consumption-price relationship, the time needed to adjust to price change, and the rate of economic growth.

4. Adelman, M.A. "The Clumsy Cartel," in Energy Journal, Vol. 1, No. 1, January 1980. Originally distributed as Working Paper MIT-EL 79-036WP.

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 cutback 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 to lose control. They will avoid the dangerous surplus of supply and so will keep prices under pressure.

5. Adelman, M.A., and H.D. Jacoby, "Alternative Methods of Oil Supply Forecasting", in R.S. Pindyck (ed.), Advances in the Economics of Energy and Resources, Vol. II, J.A.I. Press, 1979. Originally distributed as Working Paper MIT-EL 77-023WP.

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 task reduces to making the best use of the limited information that is available. Here we report on two alterntive approaches to this forecasting problem, both avowedly 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 who are the price-makers. Their groupings are not hard and fast; indeed an exporter would change from one to another camp. In this paper our focus is on the price-taker suppliers and demand functions for importers. These functions are to be incorporated into a simulation model of overall market performance.

6. Adelman, M.A. and G. Ward, "Estimation of Worldwide, Producton Costs for Oil and Gas", in J. Moroney (ed.), Advances in the Economics of Energy and Resources, Vol. III, J.A.I. Press, Spring 1980. Originally distributed as Working Paper, MIT-EL 79-058WP.

This paper presents 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 non-drilling production costs such 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 included are: special problems associated with estimating offshore platform and pipeline costs; an examination of recent claims about Saudi Arabian producton costs; North Sea production

costs calculated using unusually detailed published information, and a rough check comparing our calculated production outlays with reported outlays.

7. Agmon, T., D.R. Lessard, and J.L. Paddock, "Financial Markets and the Adjustment to Higher Oil Prices", in R.S. Pindyck (ed.), Advances in the Economics of Energy and Resources, Vol. I, J.A.I. Press, Greenwich, Conn., 1979. Originally distributed as Working Paper MIT-EL 77-039WP.

   This paper explores the linkages between the world energy and financial markets. The role of international financial markets in the adjustment of the real markets for energy is analyzed from both a conceptual and 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 for world financial markets.

8. 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 the 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 what extent to the high rates of inflation prevailing in the industrial countries. The study is divided: a theoretical analysis of OPEC's terms of trade (the model), the empirical results, and a brief summary with some significant conclusions.

9. Dailami, M. "Financial Influences on the Behavior of Oil Exporters", forthcoming (Fall 1980) in Papers and Proceedings of the IAEE/RFF Conference on International Energy Issues: June 1979. Originally distributed as Working Paper MIT-EL 789-035WP.

   This paper discusses the influence of financial considerations on the oil production policies of oil-producing countries. Other factors include technology, politics, and conservation. This study, therefore, should be viewed as only a partial analysis of oil supply determination. However, it has become increasingly

clear that the decisions of the oil-producing countries may be more heavily influenced by short-run financial considerations, such as their need for foreign financing, and their apprehension of the impact of changes in oil revenues on their domestic economies.

After discussing these issues, this paper presents a macrofinancial model of Venezuela. This is a short-run simulation model with econometrically-estimated parameters. The model's structure captures the financial elements described above. The output of the simulation runs show the effects on balance of payments, foreign borrowing, oil production and revenues, and GNP of various exogenously-specified scenarios. Although this model is for Venezuela, it is essentially an open-economy Keynesian-type model which can be applied to other countries.

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

The 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 exploration, development, and production of reservoirs. The Basin Development Model relies on a deterministic discovery decline relationship to generate an expected 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 which takes account of costs and expected 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.

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

A description of the structure of the project, methods being used, and problems of data and analysis.

12. 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.

13. Jacoby, H.D. and J.L. Paddock, "Supply Instability and Oil Market Behavior", in Energy Systems and Policy, Vol. 3, No. 4, Winter 1980, pp. 401-423. Originally distributed as Working Paper MIT-EL 79-033WP.

This paper analyzes the supply disruption in world oil markets in the winter of 1978-1979. The causes of the resultant price rise 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 of these conclusions are discussed.

14. O'Carroll, F. and J.S. Smith, "Probabilistic Methods for Estimting Undiscovered Petroleum Resources", forthcoming in J. Moroney (ed.), Advances in the Economics of Energy and Natural Resources, Volume III, J.A.I. Press, 1980. Originally distributed as Working Paper MIT-EL 80-008WP.

The problem studied in this paper is how to estimate and, if possible, set limits to the 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 their estimated recoverable reserves, and numbers of exploration wells drilled. No use is made of geological data or judgment.

Four models are constructed for detailed study, representing a range of levels of sophistication. The simplest model postulates only that discovery probabilities are proportional to field size, as indexed by millions of barrels of recoverable hydrocarbons. Greater sophistication is then added to obtain other models, by specifying a lognormal distributionof field size, a more general discovery probability law and a link between discovery rate and drilling activity. The performance of these models is examined using data for the Northern North Sea (56 - 62° North).

In some respects, different models and data lead to similar conclusions. All calculations agree that there are no more fields to be discovered in the two largest size-classes and that there are few if any undiscovered fields with recoverable reserves of 500 million barrels or above. They also agree that the majority of undiscovered fields are in the smallest class in the range considered (around 50 million barrels or less). With regard to the total volume of resources in undiscovered fields, however, different approaches give widely different results. The estimated total of hydrocarbon resources in the area, ranges from about 40 to 70 billion barrels of oil and oil equivalent, depending on the model. This is similar to the range of estimates available from various oil industry sources in recent years, using geological data and judgemental methods. These results show that even for a given model and data set, a range of uncertainty surrounds the estimates of total resources which is of the same order of magnitude as the estimate itself.

One lesson 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 improve the quality of the results obtained.

15. Pindyck, R.S. "Optimal Exploration and Production of a Nonrenewable Resource", Journal of Political Economy, October 1978. Originally distributed as Working Paper MIT-EL 77-013WP.

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. We solve this problem for competitive and monopolistic markets, and show that if the initial reserve endowment is small, the price profit will be U-shaped; at first production will increase as reserves are developed, and later production will decline as both exploratory activity and the discovery rate fall.

16. 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.

This paper is a survey of about thirty recent econometric studies of energy demand, including the international study of world energy demand done under the M.I.T. 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 to 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 had thought to be the case earlier. The paper also discusses the implications of this point for the formulation of energy policy.

17. Pindyck, R.S., "OPEC's Dilemma: How to Control Production Levels." This is an article that appeared in The Wall Street Journal, December 13, 1978.

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

18. Pindyck, R.S., The Structure of World Energy Demand, M.I.T. Press, 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, and 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 are discussed in detail. Statistical results are presented for energy demand models pertaining to each sector of use. Finally, the book discusses the relationship between the price and demand for energy and economic growth, including the implications of our studies for the impact of higher energy prices on economic growth and employment.

19. Pindyck, R.S. "The Cartelization of World Commodity Markets", American Economic Review, May 1979.

This paper discusses the likelihood of cartels spreading to other commodity markets.

20. Pindyck, R.S., "Interfuel Substitution and the Industrial Demand for Energy: An International Comparison", Review of Economics and Statistics, May 1979. Originally distributed as Working Paper MIT-EL 77-026WP.

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 of 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 other factor inputs such 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 tested. 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.

21. Pindyck, R.S., "Some Long-Term Problems in OPEC Oil Pricing", in Journal of Energy and Development, Spring 1979. Originally distributed as Working Paper MIT-EL 78-028WP.

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 twenty 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 of these questions are dealt with using our small monopolistic model of optimal cartel pricing.

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

23. Pindyck, R.S., "International Comparisons of the Residential Demand for Energy", in European Economic Review, January 1980. Originally distributed as Working Paper MIT-EL 77-027WP which 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 to any utility function and therefore does not a priori impose constraints of homotheticity, separability, or additivity on the structure of demand. These functions were estimted 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.

24. Smith, J.L. "A Probabilistic Model of Oil Discovery", forthcoming in Review of Economics and Statistics, Fall 1980. Originally distributed as Working Paper MIT-EL 80-005WP.

This paper presents a discovery model based on the notion that individual reservoirs are discovered randomly, with probability proportional to reservoir size. Our model is an adaption of Kaufman's original formulation of this problem. The changes we propose are motivated by the need for les computational demands during implementation and reduced sensitivity to data errors which are inherent in reported reserve volumes. The resulting model is applied to the North Sea petroleum province.

Estimates of the total volume of remaining reserves and the size of individual deposits are obtained and compared to estimates provided by the industry. The method of analysis presented here appears to perform well, and constitutes a useful addition to the set of tools available for economic studies of petroleum supply.

WORKING PAPERS

25. Adelman, M.A., "The Political Economy of the Middle East - Changes and Prospects Since 1973," 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 polical 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 1974-1975, and appropriate options for the U.S.

26. Adelman, M.A. and H.D. Jacoby, "Oil Prices, Gaps, and Economic Growth", MIT-EL 78-008WP, May 1978.

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

27. Adelman, M.A. and J.L. Paddock, "An Aggregate Model of Petroleum Production Capacity and Supply Forecasting", MIT-EL 79-005WP, Revised July 1980.

This paper presents a complete discussion and documentation of the M.I.T. 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 are discussed. Next, the construction of the data base is described and the data, by country segment, is 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.

28. Bradley, P., "Production of Depleting Resources: A Cost-Curve Approach", 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 cost where both production volume and production rate are taken explicitly into account. Corresponding cost curves are illustrated for the simplest situation, uniform output until resource exhaustion. Section III 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 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 postulate.

29. Carson, J., "A User's Guide to the World Oil Project Demand Data Base", MIT-EL 78-016WP, August 1978.

A description of all the data used for demand analysis in the World Oil Project. 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, information on how to access the computerized data or obtain the information in other formats included. Purchasing power parities and issues involving energy unit conversion are discussed.

30. Carson, J., W. Christian, and G. Ward, "The MIT World Oil Project Model: Documentation and User's Guide", MIT-EL 80-026WP, June 1980.

Description of the three separate models used by the World Oil Project. The demand model forecasts energy demand in the OECD countries and aggregates petroleum product demand with crude oil demand from the rest of the world, excluding planned economies. The supply model forecasts possible production scenarios for oil producers throughout the world. The integration model integrates demand and supply forecasts and allocates actual production to producers.

The paper reviews the estimation methodology and database used in constructing the models. The equations are described and the behavior summarized. Policy use of the model is described and limitations of the models are identified. Sample output is presented and the use of the simulation framework is described.

31. Dailami, M., "The Choice of an Optimal Currency for Denominating the Price of Oil", 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 earning 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.

32. Dailami, M. "Measuring the Purchasing Power of Major Currencies from OPEC's Viewpoint", MIT-EL 79-022WP, 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 as how to measure the fluctuation in the value of the dollar which 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 who are compelled to invest a relatively high proportion of their oil revenues in foreign financial assets.

In this paper our objectives are two: first, to present data on the rate of change in the purchasing power of the dollar from OPEC's viewpoint for the period 1971-1977, and to use this to measure the depreciation in OPEC's financial assets. Second, to compare the performance of the dollar with other major currencies from OPEC's point of view over the same period and to see how OPEC would have fared had currencies other than the U.S. dollar been used for oil-pricing purposes.

33. Dailami, M., "The Determination and Control of Money Supply in an Oil Exporting Country: The Iranian Experience", 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 has 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 for the economies of oi-exporting counties. 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.

In this paper our objective is to analyze the role of oil revenue in the determination and the controllability of money supply in Iran. In particular we will pursue 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 revenue 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 revenue 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.

34. Heide, R., "Log Linear Models of Petroleum Product Demand: An International Study," MIT-EL 79-006WP, February 1979.

This paper provides preliminary results on the estimation of petroleum product demands 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, with right-hand side variables of price of the particular petroleum product, per capita GDP, and lagged per capita consumption of the product.

35. Heide, R., "The Demand for Motor Gasoline: A Multi-Country Stock Adjustment Model", 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 a demand derived from distinct consumer decisions, such as gasoline price, income, and available automobile stock. Automobile stock, distance, and efficiency adjustments are all posited to take more than one period; the dynamics thus arise from this adjustment behavior.

36. Jacoby, H.D., et al., "Energy Policy and the Oil Problem: A Review of Current Issues", 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, syn-fuels 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 M.I.T. Center for Energy Policy Research, but made substantial use of data and analysis resulting from the M.I.T. World Oil Project.

37. Owsley, H., "The Effect of Increased National Oil Company Sales on OPEC and the Long Run Structure of the International Petroleum Market", MIT-EL 79-056WP, May 1979.

The effect of increased national oil company sales on the world petroleum system is examined. These sales cut into the volume of crude handled by the major international companies and will impact upon OPEC's pricing ability.

The growth of these sales is measured using annual reports and other industry statistics. Their effects on oil compnay behavior are examined from both a theoretical and an empirical standpoint. The analysis shows that the firms' behavior patterns are indeed changing, as predicted.

These changes will create pressure on OPEC producers to restrict production. Using supply/demand models developed by the M.I.T. World Oil Project, the output levels of major cartel members are simulated. These results are compared with the countries' economic needs into the late 1980s.

The simulations indicate that the OPEC core will encounter financial difficulties if current programs are continued. Alternate strategies for the cartel are discussed.

DRAFTS IN PROCESS AS OF JULY 1980

38. Adelman, M.A. and J.L. Paddock, "Endogenous Development Drilling Rates in Petroleum Supply: An Empirical Analysis", forthcoming as an MIT working paper.

This paper introduces the concept of an endogenous development drilling rate into the M.I.T. World Oil Project Aggregate Supply Model. Incorporating the concept of strictly convex adjustment costs, a dynamic programming framework is used to derive the optimal path of development drilling as a function of prices and costs. A discussion of the implications for forecasting oil productive capacity is presented.

39. Adelman, M.A. and H. Owsley, "Forecast of Crude Oil Production Capacity for Mexico", forthcoming as an MIT working paper.

This paper explores the potential oil production from Mexico through 1985. It uses a preliminary version of the disaggregated model to develop reserves, by field, and forecast their productivity curve over time. Special emphasis is put on the Reforma Region. Rig time and well-drilling scenarios are the basic driving variables of the model.

40. Agmon, T., D.R. Lessard, and J.L. Paddock. "Financing Energy Development in Developing Countries", forthcoming as an MIT working paper.

International finance is fast becoming a key element in the analysis of international energy markets and policy. Financial considerations may have important impacts on energy-related decisions of both importers and exporters, and developments in energy markets are likely to have important feedbacks to financial markets. While the relevance of finance to energy policy is clear, the research which has been conducted to date has only scratched the surface.

In this complex area of international energy finance, there is a key question which requires immediate research attention: what is the impact of international financing arrangements on the capacity and production decisions of price-taker oil-exporting developing countries and can more appropriate financial instituions and mechanisms be designed?

To answer this question, one must examine the impact of oil price uncertainty on the development plans of price-taker developing countries that require external financing for oil development (and oil wealth induced consumption), such as Mexico. It appears that the structure of internatinal financial institutions and instruments can influence the path such a country will take.

The key needed to solve the question set out above lies in possible innovations in international financial institutions and instruments. In this paper we will examine and discuss the forms this innovation may take.

41. Eckbo, P.L., "Estimating Offshore Exploration, Development and Production Costs", forthcoming as an MIT working paper.

This paper discusses the problems associated with estimating the cost parameters of the reservoir submodel of the disaggregated process approach to oil supply forecasting. Costs are estimated as a function of observable reservoir characteristics. Data generated by the investment/production history of the North Sea are used to estimate the cost relationships of the reservoir model. Engineering-type cost analysis is applied to the North Sea analysis to be able to estimate offshore development costs worldwide.

42. Dailami, M., "A Macroeconomic Model of Mexican Oil Supply", forthcoming as an M.I.T. working paper.

This paper contains an econometrically estimated macrofinancial model of Mexico. It builds on the Venezuelan model described in MIT Working Paper No. MIT-EL 79-035WP. However, the model for Mexico is more complex than that for Venezuela. Oil is a much smaller (though growing) proportion of the economy. As a result, other sectors contribute more significantly to GDP. In addition, Mexico's non-oil export base is much broader, because Mexico has advanced well beyond protected import-substitution industries. Also, the government's budgetary position is more complex, as non-oil revenues--mainly taxes--provide the bulk of total government revenue. Thus, our macrofinancial model of Mexico contains a more elaborate treatment of both non-oil exports and other government revenue in its simultaneous equation system. This system also includes an accelerator-type aggregate production function and a simple price equation.

43. Jacoby, H.D. and J.L. Paddock, "World Economic Growth and OPEC Oil", forthcoming as an MIT working paper.

A key question for analysis is what behavior might we expect on the price front by the OPEC core during the coming decade. Clearly, one must analyze the effects of price on the demand relationships, and the direct effects on income (economic growth) of price changes. These effects are important whether OPEC uses price or quantity as its mechanism for influencing markets.

We address these important questions by drawing on the work of the MIT World Oil Project model. This model incorporates both demand and supply simulations with an integrative mechanism for market clearing. From these clearing relationships we can specifiy an envelope of alternative oil price/GNP paths over time which are both consistent and realistic.

44. Paddock, J.L., "Investment Theory and the Development of Exhaustible Resources", forthcoming as an MIT working paper.

Production possiblities from discovered reserves of natural resources are determined by two key, interrelated factors: (1) the rate of investment which develops discovered reserves into proved reserves; and, (2) the rate of extraction from those proved reserves. Both these factors are intertemporal choice variables of the resource owner and the objective in this paper is to analyze them simultaneously.

Using an optimization methodology, we obtain solution paths for these two control variables which maximize the net present value of the resource. Two innovations are contained in the cost structure. First is the concept of "adjustment costs" which are incurred when the developer adjusts his capital base: (1) those which are internal to the project, and (2) those which are imperfections in the factor market.

If these frictional costs rise more than proportionately with increases in the relative rate of investment, then the optimal investment program is shown to be a distributed lead over future time periods. Without these costs, capital stock adjustment occurs instantaneously and the developer behaves in a myopic fashion, even in a world of uncertainty. Second, the model takes account of the fact that there are costs associated with the relative rate of production from reserves. Rates greater than the optimal level result in losses of proved reserves.

45. Smith, J.L., "Regional Modelling of Oil Discovery and Production", forthcoming as an MIT working paper.

This paper outlines a new method for summarizing the exploratory and production potential of an aggregated geographical region in terms of the past history of exploration and produciton at the field level. The discovery analysis describes the physical returns to exploratory drilling (marginal field size), which provide additions to the potential reserve base. Subsequently, the production analysis specifies the economic costs of bringing respective fields on stream, and also describes the likely production rates. The output of the two stages is an approximate forecast of the reserve additions and future production that are likely to arise from specified drilling programs. In both the exploratory stage and the production stage, the negative influence of resource depletion is modeled explicitly.

The analytical framework is illustrated by application to twenty-five individual regions around the world.

46. Smith, J.L. and G.L. Ward, "Maximum Likelihood Estimates of the Size Distribution of North Sea Oil Deposits", forthcoming in Proceedings of the American Statistical Association, August 1980, and Mathematical Geology, 1981.

Estimates of the ultimate resource potential of the North Sea petroleum province are derived from a probabilistic model of the discovery phenomenon. The discovery of individual deposits is treated as sampling without replacement from a target population (the underlying resource base), and with individual discovery probabilities defined in terms of deposit size. Conditional on the underlying resource base, the model specifies the likelihood of all possible sequences of discoveries. Conversely, upon observing a particular discovery sequence, it is possible to identify the underlying resource base that maximizes the likelihood of this event. The present paper examines the sensitivity of such resource estimates to the postulated form of the size distribution of deposits, and to the presumed degree of randomness inherent in the discovery process.

APPENDIX B

Cartel Behavior and Exhaustible Resource Supply:
A Case Study of the World Oil Market
NSF Grant No. DAR78-19044

Publications and Working Papers for the Period
March 1975 through June 1980

PUBLICATIONS

1. Adelman, M.A., "Constraints on the World Oil Monopoly Price," Resources and Energy, September 1978. A summary appears in Petroleum Economist, September 1977. Originally released as Working Paper MIT-EL 77-038WP, "Producers, Consumers, and Multinationals: Problems in Analyzing a Non-Competitive Market."

   The consuming nations have the power to damage or wreck the world oil monopoly, but 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 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 while 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 objectives and can be neglected.

2. Adelman, M.A., "World Supply and Demand", presented to the Canadian Society of Petroleum Geologists in Calgary, 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; effects of crude oil price changes on the world economy and on consumer-nations policies.

   Some preliminary results of the M.I.T. World Oil Project are summarized:

(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 capcity and also higher prices through the 1980's, unless the monopoly is destroyed;

(4) great uncertainty must itself be factored into the policies of business and government.

3. Adelman, M.A., "Energy-Income Coefficients: Their Use and Abuse," in Energy Economics, January 1980. Originally distributed as Working Paper MIT-EL 79-024WP.

The right way to estimate and forecast energy 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 averge coefficient is a valid if imprecise measure, but the incremental coefficient should not be used at all; it mixes up four elements. These four are: the consumption-income relationship, the consumption-price relationship, the time needed to adjust to price change, and the rate of economic growth.

4. Adelman, M.A., "The Clumsy Cartel", in Energy Journal, Vol. 1, No. 1, January 1980. Originally distributed as Working Paper MIT-EL 79-036WP.

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 to lose control. They will avoid the dangerous surplus of supply and so will keep prices under pressure.

5. Adelman, M.A., and H.D. Jacoby, "Alternative Methods of Oil Supply Forecasting", in R.S. Pindyck (ed.), Advances in the Economics of Energy and Resources, Vol. II, J.A.I. Press, 1979. Originally distributed as Working Paper MIT-EL 77-023WP.

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 task reduces to making the best use of the limited information that is available. Here we report on two alternative approaches to this forecasting problem, both avowedly 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 who are the price-makers. Their groupings are not hard and fast; indeed an exporter would change from one to another camp.

In this paper our focus is on the price-takers. Our analysis seeks an understanding of 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.

6. Adelman, M.A. and G. Ward, "Estimation of Worldwide, Producton Costs for Oil and Gas", in J. Moroney (ed.), Advances in the Economics of Energy and Resources, Vol. III, J.A.I. Press, Spring 1980. Originally distributed as Working Paper MIT-EL 79-058WP.

This paper presents 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 non-drilling production costs such 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 included are: special problems associated with estimating

offshore platform and pipeline costs; an examination of recent claims about Saudi Arabian production costs; North Sea production costs calculated using unusually detailed published information, and a rough check comparing our calculated production outlays with reported outlays.

7. Agmon, T., D.R. Lessard, and J.L. Paddock, "Financial Markets and the Adjustment to Higher Oil Prices", in R.S. Pindyck (ed.), Advances in the Economics of Energy and Resources, Vol. I, J.A.I. Press, Greenwich, Conn., 1979. Originally distributed as Working Paper MIT-EL 77-039WP.

   This paper explores the linkages between the world energy and financial markets. The role of international financial markets in the adjustment of the real markets for energy is analyzed from both a conceptual and 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 for world financial markets.

8. Cremer, J. and M.L. Weitzman, "OPEC and the Monopoly Price of World Oil", European Economic Review, Vol. 8, 1976, pp. 155-164. Originally distributed as Working Paper MIT-EL 76-015WP.

   This paper presents a dynamic model of the behavior of OPEC viewed as 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 twenty years.

9. 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 the 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 what extent to the high rates of inflation prevailing in the industrial countries. The study is divided: a theoretical analysis of OPEC's terms of trade (the model), the empirical results, and a brief summary with some significant conclusions.

10. Dailami, M. "Financial Influences on the Behavior of Oil Exporters", forthcoming Fall 1980 in Papers and Proceedings of the IAEE/RFF Conference on International Energy Issues: June 1979. Originally distributed as Working Paper MIT-EL 78-035WP.

    This paper discusses the influence of financial considerations on the oil production policies of oil-producing countries. Other factors include technology, politics, and conservation. This study, therefore, should be viewed as only a partial analysis of oil supply determination. However, it has become increasingly clear that the decisions of the oil-producing countries may be more heavily influenced by short-run financial considerations, such as their need for foreign financing, and their apprehension of the impact of changes in oil revenues on their domestic economies.

    After discussing these issues, this paper presents a macrofinancial model of Venezuela. This is a short-run simulation model with econometrically-estimated parameters. The model's structure captures the financial elements described above. The output of the simulation runs show the effects on balance of payments, foreign borrowing, oil production and revenues, and GNP of various exogenously-specified scenarios. Although this model is for Venezuela, it is essentially an open-economy Keynesian-type model which can be applied to other countries.

11. Eckbo, P.L., and J.L. Smith, "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.

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

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

13. Eckbo, P.L., The Future of World Oil, Ballinger Publishing Company, 1976. Originally distributed as Working Paper MIT-EL-017WP.

    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 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 which may reflect a competitive market structure, a monopolistic market structure or any combination of the two. Changes in the decisions rules being applied provides 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 approach.

14. Eckbo, P.L., H.D. Jacoby, and J.L. Smith, "Oil Supply Forecasting: A Disaggregated Process Approach," Bell Journal of Economics, Spring 1978. Originally distributed as Working Paper MIT-EL 77-001.

Work is under way 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 account of 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.

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

The 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 exploration, development, and production of reservoirs. The Basin Development Model relies on a deterministic discovery decline relationship to generate an expected 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 which takes account of costs and expected 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.

16. Hnyilicza, E. and R.S. Pindyck, "Pricing Policies For A Two-Part Exhaustible Resource Cartel: The Case of OPEC", European Economic Review, Vol. 8, 1976, pp. 139-154. Originally distributed as Working Paper MIT-EL-76-008WP.

    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 on 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 price path. If the shares are subject to control, optimal paths depend significantly on the relative bargaining power of each block.

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

    A description of the structure of the project, methods being used, and problems of data and analysis.

18. 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.

19. Jacoby, H.D. and J.L. Paddock, "Supply Instability and Oil Market Behavior", in Energy Systems and Policy, Vol. 3, No. 4, pp. 401-423. Originally distributed as Working Paper MIT-EL-79-033WP.

This paper analyzes the supply disruption in world oil markets in the winter of 1978-1979. The causes of the resultant price rise 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 of these conclusions for U.S. policy are discussed.

20. O'Carroll, F. and J.S. Smith, "Probabilistic Methods for Estimting Undiscovered Petroleum Resources", forthcoming in J. Moroney (ed.) Advances in the Economics of Energy and Resources, Vol. III, J.A.I. Press, 1980. Originally distributed as Working Paper MIT-EL 80-008WP.

The problem studied in this paper is how to estimate and, if possible, set limits to the 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 their estimated recoverable reserves, and numbers of exploration wells drilled. No use is made of geological data or judgment.

Four models are constructed for detailed study, representing a range of levels of sophistication. The simplest model postulates only that discovery probabilities are proportional to field size, as indexed by millions of barrels of recoverable hydrocarbons. Greater sophistication is then added to obtain other models, by specifying a lognormal distribution of field size, a more general discovery probability law and a link between discovery rate and drilling activity. The performance of these models is examined using data for the Northern North Sea (56 - 62° North).

In some respects, different models and data lead to similar conclusions. All calculations agree that there are no more fields to be discovered in the two largest size-classes and that there are few if any undiscovered fields with recoverable reserves of 500 million barrels or above. They also agree that the majority of undiscovered fields are in the smallest class in the range considered (around 50 million barrels or less). With regard to the total volume of resources in undiscovered fields, however, different approaches give widely different results. The estimated total of hydrocarbon resources in the area, ranges from about 40 to 70 billion barrels of oil and oil equivalent, depending on the model. This is similar to the range of estimates available from various oil industry sources in recent years, using geological data and judgmental methods. These results show that even for a given model and data set, a range of uncertainty surrounds the estimates of total resources which is of the same order of magnitude as the estimate itself.

One lesson 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 improve the quality of the results obtained.

21. Pindyck, R.S., "Cartel Pricing and the Structure of the World Bauxite Market", March 1977, Bell Journal of Economics, Autumn 1977. Originally distributed as Working Paper MIT-EL 77-005WP.

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.

22. Pindyck, R.S., "Gains to Producers from the Cartelization of Exhaustible Resources", The Review of Economics and Statistics, May 1978. Originally distributed as Working Paper MIT-EL 76-012WP.

The potential gains to produceres 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 account for short-term resource are measured by calculating optimal price trajectories under competition and under cartelization, and comparing the sums of discounted profits resulting from each.

23. Pindyck, R.S., "OPEC's Threat to the West", Foreign Policy, Spring 1978. Originally distributed as Working Paper MIT-EL 78-001WP.

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 possiblity of an embargo in the short term. Finally, the implications of higher energy prices for GNP growth, unemployment, and inflation in the industrialized countries is discussed. The paper concludes with a set of energy and economic policy recommendations.

24. Pindyck, R.S., "Optimal Exploration and Production of a Nonrenewable Resource", Journal of Political Economy, October 1978. Originally distributed as Working Paper MIT-EL 77-013WP.

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. We solve this problem for competitive and monopolistic markets, and show that if the initial reserve endowment is small, the price profit will be U-shaped; at first production will increase as reserves are developed, and later production will decline as both exploratory activity and the discovery rate fall.

25. 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.

This paper is a survey of about thirty recent econometric studies of energy demand, including the international study of world energy demand done under the M.I.T. 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 to 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 had thought to be the case earlier. The paper also discusses the implications of this point for the formulation of energy policy.

26. Pindyck, R.S., "OPEC's Dilemma: How to Control Production Levels." This is an article that appeared in The Wall Street Journal, December 13, 1978.

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

27. Pindyck, R.S., The Structure of World Energy Demand, M.I.T. Press, 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, and 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 are discussed in detial. Statistical results are presented for energy demand models pertaining to each sector of use. Finally, the book discusses the relationship between the price and demand for energy and economic growth, including the implications of our studies for the impact of higher energy prices on economic growth and employment.

28. Pindyck, R.S. "The Cartelization of World Commodity Markets", American Economic Review, May 1979.

This paper discusses the likelihood of cartels spreading to other commodity markets.

29. Pindyck, R.S., "Interfuel Substitution and the Industrial Demand for Energy: An International Comparison", Review of Economics and Statistics, May 1979. Originally distributed as Working Paper MIT-EL 77-026WP.

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 of 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 other factor inputs such 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 logic models, were also tested. 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.

30. Pindyck, R.S., "Some Long-Term Problems in OPEC Oil Pricing", in Journal of Energy and Development, Spring 1979. Originally distributed as Working Paper MIT-EL-78-028WP.

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 twenty 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 of these questions are dealt with using our small monopolistic model of optimal cartel pricing.

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

32. Pindyck, R.S., "International Comparisons of the Residential Demand for Energy", in European Economic Review. January, 1980. Originally distributed as Working Paper MIT-EL 77-027WP which 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 to any utility function and therefore does not a priori impose constraints of homotheticity, separability, or additivity on the structure of demand. These functions were estimted 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.

33. Smith, J.L. "A Probabilistic Model of Oil Discovery", forthcoming in Review of Economics and Statistics, Fall 1980. Originally distributed as Working Paper MIT-EL 80-005WP.

This paper presents a discovery model based on the notion that individual reservoirs are discovered randomly, with probability proportional to reservoir size. Our model is an adaptation of Kaufman's original formulation of this problem. The changes we propose are motivated by the need for less computational demands during implementation and reduced sensitivity to data errors which are inherent in reported reserve volumes. The resulting model is applied to the North Sea petroleum province.

Estimates of the total volume of remaining reserves and the size of individual deposits are obtained and compared to estimates provided by the industry. The method of analysis presented here appears to perform well, and constitutes a useful addition to the set of tools available for economic studies of petroleum supply.

WORKING PAPERS AND REPORTS

1. Adelman, M.A., "The Political Economy of the Middle East - Changes and Prospects Since 1973," 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 1974-1975, and appropriate options for the U.S.

2. Adelman. M.A. and H.D. Jacoby, "Oil Prices, Gaps, and Economic Growth", MIT-EL 78-008WP, May 1978.

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

3. Adelman, M.A. and J.L. Paddock, "An Aggregate Model of Petroleum Production Capacity and Supply Forecasting", MIT-EL 79-005WP, Revised July 1980.

   This paper presents a complete discussion and documentation of the M.I.T. World Oil Project Aggregate Supply Model. First, the theoretical development and methodology are presented. The relationsips between geologic and economic characteristics are analyzed and a system of equations representing the inertial process model are discussed. Next, the construction of the data base is described and the data, by country segment, is 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.

4. Agmon, T., D.R. Lessard and J.L. Paddock, "The International Finance Aspects of OPEC: An Informational Note", 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 the 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.

   First, 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 is presented. There follows a brief discussion and extensive source listing of the various financial proposals which arose to deal with these financial surpluses. Concluding sections present a chronology of the major international financial events which led up to the 1973 price rise and thereafter, and a summary of the subsequent changes in U.S. corporate tax policy.

5. Agmon, T., D. R. Lessard ad J.L. Paddock, "Accommodation in International Capital Markets: Paying for Oil, Financing Oil and the Recyling of Oil Funds", 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. We analyze the specific roles of primary and secondary recycling of oil funds 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. We conclude with a general equilibrium model which derives the supply behavior of an oil-producing country.

6. Beall, A.O., "Dynamics of Petroleum Industry Investment in the North Sea", 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 which 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 judgemental 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.

7. Bradley, P., "Production of Depleting Resources: A Cost-Curve Approach", 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 desciptive 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 cost where both production volume and production rate are taken explicitly into account. Corresponding cost curves are illustrated for the simplest situation, uniform output until resource exhaustion. Section III 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 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 postulate.

8. Carson, J., "A User's Guide to the World Oil Project Demand Data Base", MIT-EL 78-016WP, August 1978.

A description of all the data used for demand analysis in the World Oil Project. 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, information on how to access the computerized data or

obtain the information in other formats included. Purchasing power parities and issues involving energy unit conversion are discussed.

9. Carson, J., W. Christian, and G. Ward, "The MIT World Oil Model: Documentation and User's Guide", MIT-EL 80-026WP, June 1980.

Description of the three separate models used by the World Oil Project. The demand model forecasts energy demand in the OECD countries and aggregates petroleum product demand with crude oil demands from the rest of the world, excluding planned economies. The supply model forecasts possible production scenarios for oil producers throughout the world. The integration model integrates demand and supply forecasts and allocates actual production to producers.

The paper reviews the estimation methodology and database used in constructing the models. The equations are described and the behavior summarized. Policy use of the model is described and limitations of the models are identified. Sample output is presented and the use of the simulation framework is described.

10. Crandall, M.S., "The Economics of Iranian Oil", MIT-EL 75-003WP, March 1975.

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

Next the paper 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).

11. Dailami, M., "The Choice of an Optimal Currency for Denominating the Price of Oil", 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 earning 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.

12. Dailami, M., "The Determination and Control of Money Supply in an Oil Exporting Country: The Iranian Experience", 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 has 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 for the economies of oil-exporting counties. 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.

In this paper our objective is to analyze the role of oil revenue in the determination and the controllability of money supply in Iran. In particular we will pursue 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 revenue 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 revenue 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.

13. Dailami, M. "Measuring the Purchasing Power of Major Currencies from OPEC's Viewpoint", MIT-EL 79-022WP, 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 as how to measure the fluctuation in the value of the dollar which 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 who are compelled to invest a relatively high proportion of their oil revenues in foreign financial assets.

In this paper our objectives are two: First, to present data on the rate of change in the purchasing power of the dollar from OPEC's viewpoint for the period 1971-1977, and to use this to measure the depreciation in OPEC's financial assets. Second, to compare the performance of the dollar with other major currencies from OPEC's point of view over the same period and to see how OPEC would have fared had currencies other than the U.S. dollar been used for oil-pricing purposes.

14. Eckbo, P.L., "OPEC and the Experience of Previous International Commodity Cartels", 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 countries. Cartel "success" was defined in terms of the ability of the organization to raise 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 which 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 who did succeed in raising prices for four years or more were characterized by markets where the concentration of production was high, the demands inelastic, the cartels market share was high and the membership had cost advantages over outsiders. An additional characteristic of the successful cartels was that governments were not directly involved in their operations. 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.

15. Heide, R., "Log Linear Models of Petroleum Product Demand: An International Study," MIT-EL 79-006WP, February 1979.

This paper provides preliminary results on the estimation of petroleum product demands 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, with right-hand side variables of price of the particular petroleum product, per capita GDP, and lagged per capita consumption of the product.

16. Heide, R., "The Demand for Motor Gasoline: A Multi-Country Stock Adjustment Model", 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 a demand derived from distinct consumer decisions, such as gasoline price, income, and available automobile stock. Automobile stock, distance, and efficiency adjustments are all posited to take more than one period; the dynamics thus arise from this adjustment behavior.

17. Jacoby, H.D., et al., "Energy Policy and the Oil Problem: A Review of Current Issues", 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, syn-fuels 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 M.I.T. Center for Energy Policy Research, but made substantial use of data and analysis resulting from the M.I.T. World Oil Project.

18. Members of the M.I.T. World Oil Project, "Progress on Analysis of the World Oil Market," MIT-EL 75-015WP, October 1975.

This is the 6 month report on the Project. It presents an overview of the research design and the details of work in progress as of Fall, 1975, including the demand analysis, the supply studies, and the various studies of market-clearing processes. It also includes a revised version of the work schedule presented in the original proposal.

19. Members of the M.I.T. 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.

20. Owsley, H., "The Effect of Increased National Oil Company Sales on OPEC and the Long Run Structure of the International Petroleum Market", MIT-EL 79-056WP, May 1979.

The effect of increased national oil company sales on the world petroleum system is examined. These sales cut into the volume of

crude handled by the major international companies and will impact upon OPEC's pricing ability.

The growth of these sales is measured using annual reports and other industry statistics. Their effects on oil company behavior are examined from both a theoretical and an empirical standpoint. The analysis shows that the firms' behavior patterns are indeed changing, as predicted.

These changes will create pressure on OPEC producers to restrict production. Using supply/demand models developed by the M.I.T. World Oil Project, the output levels of major cartel members are simulated. These results are compared with the countries' economic needs into the late 1980s.

The simulations indicate that the OPEC core will encounter financial difficulties if current programs are continued. Alternate strategies for the cartel are discussed.

21. Supply Working Group, M.I.T. World Oil Project, "Supply Forecasting Using Disaggregated Pool Analysis", 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 which predicts the arrival and size of new discoveries and a reservior development submodel which determines the rate at which discovered resources become available as economic reserves.

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

Implementaton 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, so as to reveal both the flexibility and the limitations of the analytical procedure in its present form.

APPENDIX C

List of Meeting, Lectures, Conferences, and Testimony by Project Personnel

for the period of July 1, 1978 through June 30, 1980

M.A. Adleman

July 1978	Gave a talk to the Canadian Society of Petroleum Geologists 50th Anniversary. Presented a paper entitled, "World Supply and Demand," Calgary, Canada.
October 1978	World Oil Meeting sponsored by the M.I.T. Center for Energy Policy research. Session Chairman on various topics key to world oil market analysis. Durham, New Hampshire.
November 1978	Invited lecturer in Korea and Japan, and presented the following:
	Gave talks on world supply and demand and overall work on the World Oil Project.
	Gave an address to Korean Development Institute in Seoul.
	Gave an Public Lecture under the auspices of Korean Traders Association and NAWAY Business Journal in Seoul Entitled "Energy and Oil Prospects."
	Gave an address in Japan on World wide energy supply and demand. Lectured to Committee for Energy Policy Promotion (CEPP).
	Had closed meetings with the Institute of Energy Economics (IEE).
	Had newpaper interviews with Tokyo Shimbun and Tokyo Keizai Weekly.
January 1979	Speech and Seminar on World Oil to Inter-American World Affairs Council, Session on International Oil.
February 1979	Talk on Demand Growth to Energy Policy of Norway, Session on International Oil and Gas.
	Annual Meeting of Council on Economics of AIME (American Institute of Mining Metallurgical & Petroleum Engineers). Received Award for contributions to Mineral Economics.

March 1979	Talk and Seminar at Brandeis University on Mexican Oil.
	Testimony before a Sub-Committee of The House of Representatives Appropriations Committee on Domestic Energy Policy.
March-April 1979	Northwestern University Transportation Center, Sessions on International Oil Supply and Demand.
April 1979	Talk on International Oil to Chicago Council on Foreign Relations.
	Talk on Domestic and International Energy Policy on "Firing Line" (William F. Buckley, Jr.)
	Talk on International Oil Markets to University of Virginia Graduate Economics Association.
May 1979	Session organized by Congressional Research Service for Group of thirty Representatives.
June 1979	Annual Meeting of International Association of Energy Economists, Talk on Next Decade in International Oil Markets.
	Appearance for Sub-Committee on Environment Energy and Natural Resources, U.S. House of Representatives.
	Various meetings: Advisory Council of Gas Research Institute.
	President-elect, International Association of Energy Economists.
August 1979	Testimony, Court-appointed expert, before U.S. District Court, Central District of California (Hon. A. Andrew Houk), in International Association of Machinists vs. OPEC, et al.
September 1979	Testimony, U.S. Senate, Committee on Energy & Natural Resources, on proposals relating to import control, government purchasing of oil, and stockpiling.
October 1979	EPRI (Electric Power Research Institute) Seminar: speaker on oil and gas supply.
	Talk, U.S. Department of State, Foreign Service Institute, on international oil.
	Testimony, U.S. House of Representatives, Sub-Committee on Africa, on elation of African countries to world oil market and U.S. supply.
	Talk and Seminar, Pennsylvania State University, on oil supply, policy.

December 1979	Talk, Inter-American Defense College, (Department of Defense) on international oil.
	Talk, D.R.I., "International Oil in the Eighties".
	Chairman, session on international oil pricing, joint meeting, IAEE and American Economic Association.
	Paper on Mexican petroleum at joint session, AEA and Council on Economics of American Institute of Mining Metallurgical and Petroleum Engineers (AIME).
January 1980	Talk to Boston chapter, IAEE on oil policy.
	Comments rendered (by invitation) to GAO, paper on taxation of foreign operations of U.S. companies.
February 1980	Paper at conference in Cologne, Germany, Institute for Energy Economics Research (illness prevented trip).
	Talk to Bank of America research group on international oil market.
March 1980	Talks at Reed College on oil policy and on energy demand analysis.
	Talk at Boston College Energy Forum on long run energy prospects.
	Consultant (for balance of year) to U.S. Department of Justice, matters involving international oil.
April 1980	Talk at Wesleyan Unviersity on oil policy.
	Talk at Northwestern University Transportation Center, sessions on energy and oil supply and demand.
	Talk at Institut August Comte (Paris) on energy outlook.
May 1980	World Oil Meeting sponsored by Energy Policy Research Center, M.I.T. , rapporteur on recent market changes.
June 1980	Final address at Second Annual IAEE International Conference on International Energy Issues, Churchill College, Cambridge University (England).

Interviews:	New York Times
	Wall Stret Journal
	Business Week
	Newsweek
	Time
	Danish Television
	Milwaukee Journal
	Los Angeles Times
	Nihon Keizei Shimbun (Tokyo)
	Korean Television
	Chicago Tribune
	British Broadcasting Corporation
	"Wall Street Week" (Public Broadcasting Service)
	Il Mondo (Milan)

M. Dailami

March 1979	Presented paper entitled, "The Influence of Financial Considerations on the Behavior of Oil-Exporting Countries," at Energy Policy Workshop, M.I.T.

H.D. Jacoby

June 1978	Participation in panel to review a CIA analysis of the world oil prospects, Warrentown, Virginia.
	Address to the National Computer Conference on domestic and international energy issues, Anaheim, California.
	Presentation of M.I.T. World Oil work to executives of British Petroleum, London, England.
	Participation in discussion of energy issues with members of the energy group, Churchill College, Cambridge, England.

October 1978	Participation in Exxon sponsored meeting of energy researchers from five universities, Houston Texas.
	World Oil Meeting Sponsored by the M.I.T. Center for Energy Policy Research . Session Chairman on various topics key to world oil market analysis. Durham, New Hampshire.
November 1978	Member of the Coordinating Subcommittee of the National Petroleum Council's Committee on U.S. Refinery Flexibility.
December 1978	Testimony on Alternatives for Oil Import Reduction at a Public Meeting on National Energy Plan II, Boston, Massachusetts.
February 1979	Participation in workshop on The Emergency Energy Management Information System, conducted in the Energy Information Administration, U.S. Department of Energy.
April 1979	World Oil Meeting (II) sponsored by the M.I.T. Center for Energy Policy Research, Boston, Massachusetts.
May 1979	Presentation of Paper on world oil markets presented to IAEE/REF meeting on world energy, Washington, D.C.
	Presentation of paper on North American trade in Gas, to the International Gas Union, 14th World Gas Congress, Toronto, Canada.
	Presentation of paper on world oil markets and U.S. Energy Policy, to the Eastern Economics Association, Boston, Massachusetts.
July 1979	Lectures on international energy economics and policy to the Shanghai Institute of Mechanical Engineering, Jiaotong University (Xian) and the Peoples University (Peking), Peoples Republic of China.
November 1979	Participant in conference on Energy Prices, Inflation and Economic Activity, sponsored by the M.I.T. Center for Energy Policy Research, Cambridge, Massachusetts.
	Presented an address on "Energy Prospects for the 1980s" to a meeting of the American Council of Life Insurance, Chicago, Illinois.
December 1979	Presented seminar on "Changing Oil Markets and U.S. Energy Security" to Center for Science and International Affairs and Center for International Affairs, Harvard University.

January 1980	Participation in study of world oil models carried out by the Energy Modeling Forum, Stanford University.
	Participation in National Governors Conference, meeting on "State Strategies for Energy Security," Little Rock, Arkansas.
May 1980	Talk on "Implications of Changing Oil Market Structure," to the International Association of Energy Economics, Boston Chapter.
	Participation in conference on World Oil Markets, sponsored by the M.I.T. Center for Energy Policy Research, Cambridge, Massachusetts.
	Participation in workshop on energy security, John F. Kennedy School of Government, Harvard University.
Interviews:	National Public Radio
	Los Angeles Times
	Nihong Keizei Simbun (Tokyo)

J.L. Paddock

October 1978	World Oil Meeting sponsored by the M.I.T. Center for Energy Policy Research. Session Chairman on various topics key to world oil market analysis. Durham, New Hampshire.
November 1978	Paper Presented on Aggregate Supply Model to the Southern Economic Association Meetings, Washington, D.C.
November 1978-June 1980	Member of the Coordinating Subcommittee of the National Petroleum Council's Committee on U.S. Refinery Flexibility. Attended numerous meetings of this subcommittee and presented World Oil Project model results.
December 1978	Particpant in the Energy Modeling forum (Stanford University)Study #5 on U.S. Oil and Gas Supply Models.
January 1979	Model Participation in EMF Study #5, at the Energy Modeling Forum - Stanford University. Discussed World Oil.
February 1979	Presented paper on Aggregate Model of Oil Supply of MIT-World Oil Project at Brookhaven Seminar on Oil Supply, Washington, D.C.

March 1979	Presented World Oil Project model methodology and results to several universities, research institutes, government ministries, and industrial corporations. Tokyo, Japan.
April 1979	Represented World Oil Model in discussions of world oil markets, at MIT-Center for Energy Policy Research meeting in Boston. Session chairman on World Financial System discussions.
May 1979	Presented and discussed Aggregate Model of Oil Supply Methodology and Forecasts to Energy Modeling Forum - Houston, Texas.
June 1979	Involved in presenting two working papers on oil supply analysis at IAEE/REF meetings, Washington, D.C.
	Discussed oil supply modeling aspects affecting U.S. refinery-flexibility study, and provided MIT-World Oil Project forecasts at National Petroleum Council, Washington D.C.
July 1979	Presented World Oil Model description and results to members of all Latin American countries' energy departments. These officials were visiting M.I.T. under auspices of U.S. Department of State. Cambridge, Massachusetts.
August 1979	Attended Energy Modeling Forum Study #5 meetings at M.I.T. Presented analytic results of World Oil Model. Cambridge, Massachusetts.
September 1979	Presented World Oil Model description and results to approximately thirty graduate students from the Norwegian School of Economics and Business Administration. Cambridge, Massachusetts.
October 1979	Discussed energy economics and modeling with visiting officials of the Taiwanese Department of Energy. Cambridge, Massachusetts.
	Presented a seminar on financial model results of the World Oil Project to members of U.S. Department of Energy, U.S. Treasury, and other government organizations. Washington, D.C.
November 1979	World Oil Meeting sponsored by M.I.T. Center for Energy Policy Research. Session Chairman on international financial system discussions. Cambridge, Massachusetts.
	Presented seminar on World Oil Model analytic results at the St. Louis University Conference of International Business. St. Louis, Missouri.

	Attended Energy Modeling Forum Study #5 meetings. Discussion of analytic results of World Oil Model. Washington, D.C.
February 1980	Attended National Petroleum Council meetings of Coordinating Subcommittee on U.S. Refinery Flexibility Study. Discussed results of oil model forecasting. San Francisco, California.
	Discussed energy economics and modeling with visiting officials of the Colombian Department of Energy Planning. Cambridge, Massachusetts.
Mrch 1980	Discussed energy economics and modeling with visitng officials of the Norwegian Department of Economic Analysis and Planning. Cambridge, Massachusetts.
April 1980	Organized conference and served as Session Chairman for meetings of visiting Japanese energy researchers. The conference objective was to exchange research ideas and results between Japanese and U.S. scientists studying energy matters. Cambridge, Massachusetts.
May 1980	World Oil Meeting sponsored by M.I.T. Center for Energy Policy Research. Session Chairman on strains in the international financial system and politics. Cambridge, Massachusetts.
	Attended National Petroleum Council meetings of Coordinating Subcommittee on U.S. Refinery Flexibility Study. Discussed results of oil model forecasting. Washington, D.C.
June 1980	Presented a paper on analytic results of the World Oil Model to the national convention of the American Institute of Chemical Engineers. Philadelphia, Pennsylvania.

R.S. Pindyck

December 1978	Gave a talk on "Energy Demand and Energy Policy: What Have We Learned?" at the International Scientific Forum on an Acceptable World Energy Future, Miami, Florida.
March 1979	Seminar on world energy demand at Tel-Aviv University, Tel-Aviv.
May 1979	Presentation of a paper, "Model of Resource Exploration and Production Under Uncertainty," conference on Energy Exploration, New York University, New York.

June 1979	Gave a talk on "Energy Prices, Energy Demand, and the Impact on American Economic Growth," Conference of the International Association of Energy Economists, Washington, D.C.

G. Ward

October 1978	Gave a talk at an Energy Modeling Forum meeting at the John F. Kennedy School of Government, Harvard University, on energy demand elasticities in the World Oil Project model.

APPENDIX D

M.I.T. Center for Energy Policy Research
Conferences on the World Oil Market

Attached are meeting schedules and lists of participants for conferences on the world oil market. All costs of these conferences were paid by the M.I.T. Center for Energy Policy Research. The conference's preparation, including discussion memoranda, data analysis results, and discussion leadership, was drawn primarily from research carried out under N.S.F. sponsorship

SCHEDULE

M.I.T. Center for Energy Policy Research
World Oil Meeting
October 20 - 28, 1978
New England Center
Durham, New Hampshire

Friday, October 20

5:30 - 8:30 p.m. - Varied arrivals at New England Center, Durham, New Hampshire

- Registration

- Reception and Buffet Supper (close at 8:30)

Saturday, October 21

7:30 - 8:30 a.m. - Breakfast Buffet

8:45 - 10:15 a.m. - Net Demand on OPEC

Initiator - Henry Jacoby

Comments - Tony Copp, Jim Hanson

Moderator - Loren Cox

10:15 - 10:30 a.m. - Coffee Break

10:30 - 12:00 - Strength of the International Financial/Trade/Growth System

Initiator - Jim Paddock

Comments - Andrew Crockett, Scott Pardee

Moderator - Loren Cox

12:00 - 1:00 p.m. - Break & Luncheon Buffet

1:00 - 2:30 p.m. - OPEC Capacity Creation and Price Formation

Initiator - Morry Adelman

Comments - John Mitchell, Jack Hartshorn

Moderator - Loren Cox

2:30 - 2:45 p.m. - Coffee Break

Page Two

2:45 - 4:15 p.m. - Oil Security

Initiator - Morry Adelman

Comments - Ted Moran

Moderator - Loren Cox

4:30 - 6:00 p.m. - Spillover session from 4 topics, and setting of next day format

7:00 - 8:00 p.m. - Open Bar

8:00 - 9:00 p.m. - Dinner

- Evening open for informal or formal discussion on day's topics

Sunday, October 22

7:30 - 8:15 a.m. - Continental Breakfast

8:15 - 11:00 a.m. - Discussion of U.S. policy implications and alternatives suggested by previous day's discussions

11:00 - 1:00 p.m. - Brunch, check-out, departure for flights from Boston, etc.

AGENDA

M.I.T. Center for Energy Policy Research
World Oil Meeting
April 5-6
Ramada Airport Inn
Boston, Massachusetts

Thursday, April 5

5:00 - 6:30 p.m.	Arrivals and registration, Airport Ramada Inn, Boston
6:30 - 7:00	Open bar
7:00 - 8:00	Dinner
8:00 - 9:30	Recent Developments in Supply, Demand and Price Initiator - Henry Jacoby Comments - Jim Hanson Moderator - Loren Cox

Friday, April 6

7:45 - 8:00 a.m.	Continental breakfast
8:00 - 10:00	Effects on International Finance, Trade and Growth Initiator - Jim Paddock Comments - Scott Pardee Moderator - Loren Cox
10:00 - 10:15	Coffee break
10:15 - 12:00	Outlook for OPEC Capacity, Supply and Price Initiator - Morry Adelman Comments - Tony Copp Moderator - Loren Cox
12:00 - 1:00 p.m.	Lunch and check out
1:00 - 2:15	Outlook ... (continued from morning)
2:15 - 2:30	Coffee break
2:30 - 4:30	Security of Supply Initiator - Henry Jacoby Comments - Ted Moran Moderator - Loren Cox
4:30 - 5:00	Summary comments
5:00	Depart for airport, etc.

AGENDA

M.I.T. CENTER FOR ENERGY POLICY RESEARCH

World Oil Market Meeting

May 18-19, 1980

Hyatt Regency Hotel
Cambridge, Mass.

Sunday, May 18

5:00 - 6:00 p.m.	Varied Arrivals and Check In
6:30 - 7:15 p.m.	Reception (Open Bar) - Harvard Prefunction Room
7:15 - 8:00 p.m.	Dinner - John Adams Room
8:00 - 10:00 p.m.	"World Market Behavior in Recent Months." (John Adams Room)
	Presentation: M. Adelman Comment: J. Hanson Moderator: L. Cox

Monday, May 19

7:00 - 8:00 a.m.	Breakfast - Harvard Prefunction Room and Check Out (Luggage may be given to any Bell Captain)
8:00 - 10:00 a.m.	"Recent Changes in World Oil Market Structure - Implications for Flexibility, Security and Price Stability." (John Q. Adams Room)
	Presentation: H. Jacoby Comments: P. Coggins B. Sachs Moderator: L. Cox
10:00 - 10:15 a.m.	Coffee Break
10:15 - 12:30 p.m.	"Strains on World Finance and Politics."
	Presentation: J. Paddock Comments: T. Moran A. Crockett Moderator: L. Cox
12:30 - 1:30 p.m.	Lunch - Molly Pitcher Room
1:30 - 3:30 p.m.	"Policy Responses to Uncertainty."
	Presentation: T. Teisberg Comment: A. Alm Moderator: L. Cox
3:30 p.m.	Adjourn/Departure

AGENDA

M.I.T. CENTER FOR ENERGY POLICY RESEARCH

RESEARCH & POLICY ISSUES IN THE CONTEXT OF WORLD OIL MARKET DEVELOPMENTS

November 16-18, 1980

Sunday, November 16

6:00 - 7:00 p.m.		Cocktails
7:00 - 8:00 p.m.		Dinner
8:00 - 9:30 p.m.	(Blue)	"Energy Prices, the Economy, the Environment and the Individual: A Research Preview"
		Presentation: David Wood Moderator: Loren Cox

Monday, November 17

7:30 - 8:30 a.m.		Breakfast
8:30 -10:30 a.m.	(Yellow)	"Recent Developments in World Oil Markets"
		Presentation: Morris Adelman Thomas Neff Comments: Brice Sachs Lawrence Goldstein Moderator: Loren Cox
10:30 -10:45 a.m.		Coffee Break
10:45 -12:45 p.m.		"The Oil Outlook Beyond the 1980's"
		Presentation: Henry Jacoby Comments: John V. Mitchell Moderator: Loren Cox
12:45 - 1:45 p.m.		Lunch
1:45 - 5:00 p.m.	(Pink)	"Energy Legislative and Regulatory Agendas: The Next Two Years"
		Presentation: Loren Cox Comments: Steven Hickok Frank Potter Walter Schroeder Jan Vlcek

Evening Free

Tuesday, November 18

7:30 - 8:15 a.m.		Breakfast
8:15 -12:00 noon	(Green)	"Synfuels: Prospects and Problems"
		Presentation: Arthur Wright David White
		Comments: Jim Harlan Daniel Luecke
		Moderator: Loren Cox
12:00 -12:45 p.m.		Luncheon and Departure

List of Participants in Back (Canary)

ATTENDEES OF OCTOBER 20, 21, AND 22 MEETING

Morris A. Adelman	Professor of Economics Massachusetts Institute of Technology
*Ben C. Ball, Jr.	CEPR Liaison Gulf Oil Corporation
*Joan T. Bok	Vice President New England Electric system
Jerry M. Brady	Director, Subcommittee on Energy Joint Economic Committee
*David Claydon	President B.P. North America Trading Inc..
E. Anthony Copp	Partner Salomon Brothers, Inc.
Loren C. Cox	Executive Director, CEPR, Energy Laboratory Massachusetts Institute of Technology
Andrew Crockett	Assistant Director, Middle East International Monetary Fund
*Mary H. Dawson	Massachusetts Chairperson League of Women Voters of the United States
Theodore R. Eck	Chief Economist Standard Oil Company
Herman T. Franssen	Director of the Office of Market Analysis Office of International Affairs Department of Energy
Grenville Garside	Staff Director Senate Energy Committee
Darius Gaskins	Deputy Assistant Secretary, Policy Analysis Department of Energy
Barnet Groten	Director, Research and Technology Texas Eastern Transmission Corporation

David E. Gushee	Specialist, Energy Policy, Congressional Research Service Library of Congress
*Ernst R. Habicht, Jr.	Director, Energy Program Environmental Defense Fund
*James W. Hanson	Chief Economist Exxon Corporation
Jack Hartshorn	Director & Vice President, Eastern Hemisphere Jensen Associates Inc.
*D. Dickinson Henry	Deputy Director of Research Massachusetts Audubon Society
Hendrick Houthakker	Professor of Economics Harvard University
Henry D. Jacoby	Director, CEPR, Energy Laboratory Massachusetts Institute of Technology
Helen Junz	Deputy Assistant Secretary for Commodities & National Resources Treasury Department
*Ike C. Kerridge, Jr.	Vice President, Stockholder Relations & Economist Hughes Tool Company
Daniel D. Luria	Research Associate United Auto Workers
John V. Mitchell	Head of Policy Review Unit British Petroleum
Theodore H. Moran	Professor, School of Foreign Service Georgetown University
Lincoln Moses	Administrator Energy Information Administration

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