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FINAL REPORT TO THE
NATIONAL SCIENCE FOUNDATION

of the project on

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

(NSF Grant No. DAR 78-19044)

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M.I.T. Energy Laboratory, International Energy Studies Program, in
association with the Sloan School of Management and the Department of
Economics.

PROJECT SUMMARY

This project has been concerned with the development of improved methods of analysis of world oil supply. In particular, an effort has been made to develop methods which integrate the geology and microeconomics of exploration and production, and financial effects on oil investment. The effort has been a continuation of previous NSF-sponsored research on the world oil market.

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1. INTRODUCTION

1.1 Project History

The World Oil Project has been carried out by the M.I.T. Energy Laboratory in association with the Sloan School of Management and the Department of Economics. Started in the summer of 1973, the project received support from the National Science Foundation beginning March 1, 1975. The original proposal on "Analysis of the World Oil Market" was for a three-year effort, and the initial NSF funding was for eighteen months: March 1, 1975 to August 31, 1976 (NSF Grant No. SIA75-00739). Subsequently, a continuation proposal was approved, providing a budget for the period September 1, 1976 through February 28, 1978. Continuing NSF support was received for the period July 1, 1978 through June 30, 1980, under a project entitled, "Cartel Behavior and Exhaustible Resource Supply: A Case Study of the World Oil Market" (NSF Grant No. DAR78-19044).

The current project is an extension of this last grant, for the period August 1, 1980 through January 30, 1983. Appendix A lists (with abstracts) the publications and working papers produced in connection with this project during the grant period. Appendix D lists (with abstracts) the publications and working papers from this NSF-sponsored activity over the entire period March 1975 through January 1983.

The work of this NSF-sponsored project has been led by two 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

Over the course of the project several other M.I.T. faculty and staff have contributed. Also, students have played a significant role in the research; during the period covered by this report, approximately a half-dozen graduate students either have been employed as research assistants, for periods ranging from a semester to the duration of the project, or have written graduate theses on topics associated with 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 policies, energy taxation, tariffs and quotas, and the national program of energy R&D. 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 this project has been to develop improved methods and data--and a better understanding of the characteristics of this market--to aid in the analysis of likely developments over the next few decades. The oil market presents a continually developing challenge to understanding and analysis. Prices and contractual agreements have

undergone radical change in the past few years. The potential capacity for oil production in key areas of the world, and the motivation of governments to produce 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 energy policy. 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 of the likely 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. In addition to the publications and working papers, other methods have been used to achieve this dissemination, as discussed in Section 3 below.

2. SUMMARY OF WORK

During the course of this grant we have carried out research on a variety of related tasks as outlined in our proposal, and as amended by our letter of May 8, 1980. These tasks are:

Task 1. Supply Model Development

Subtask 1.1 Integration of Supply Models

Subtask 1.2 Improved Data Methods

Task 2. Integration of Supply Model and Financial Analysis

Subtask 2.1 Country Macrofinancial Model Development

Subtask 2.2 Linkage of Oil Production and Macrofinancial Models

This section describes the work performed, and results achieved, under each task.

Task 1. Supply Model Development

Subtask 1.1 Integration of Supply Models

This task involved the linking together of "exploration-discovery" and "development-production" models into an integrated framework of supply analysis. The need for this integration was to be seen in earlier supply models, which were weak in the treatment of geologic-discovery characteristics, and in the fact that they presumed homogeneity of costs within a producing region--both across fields and through time [D-14, D-15, D-55].* Another improvement which we sought was the forging of a

* Numbers in brackets refer to project publications and working papers which are listed, with abstracts, in Appendices A and D. Appendix A concerns the work produced under this grant, from July 1980 to January 1983. Appendix D presents the entire history of publication of NSF-sponsored work since 1975.

practical link between our analysis of oil production, and developments in the analysis of the exploratory process [D-21, D-24, D-34, D-50].

The results of this work are presented in a paper by Smith and Paddock on "Regional Modeling of Oil Discovery and Production" [A-17]. In the new model the supply forecasting process is divided into two stages. First, there is treatment of oil discovery: data on previous history and estimates of ultimate recoverable reserves are used to construct an analysis of the returns to future exploratory drilling. This stage then yields additions to the potential base of proven reserves which take account of the phenomenon of "discovery decline." The work is backed up by a continuing effort on more detailed analyses of the discovery process, as reported by Smith and Ward [A-18]. The resulting model is designed to make the best possible use of the limited data that are available on a worldwide basis.

Given the results, discriminated in terms of field size, the second stage of the procedure brings in data on development cost, and describes the likely profile of supply--including the common phenomenon of "production decline."

The paper incorporates new estimates of development cost by field size. The overall analytical framework has been tested in an application to 37 major oil-producing regions, onshore and offshore. The results are very encouraging, and consideration is being given to the conversion of the M.I.T. aggregate supply analysis to this method. As part of this work the existing worldwide aggregate supply model was more fully documented in a paper by Ward [A-22].

An effort was made to incorporate financial effects and valuation in the supply analysis process. The Black-Scholes financial option model

was adapted to analyze company bidding, valuation, and development behavior on offshore U.S. tracts. This model incorporates the previous work on geologic and cost analysis with market information on the value of hydrocarbon reserves. The results are very encouraging and are reported in a paper by Paddock, Seigel and Smith [A-21].

Subtask 1.2 Improved Data Methods

The main focus of this subtask has been the development of concepts and methods which would allow more accurate analysis and measurement of production capacity, drilling and costs. This has been an ongoing activity in the project, and earlier work was carefully documented. A paper by Adelman and Ward [A-11] presents a methodology for estimating drilling and equipping costs, and another paper by Carson, Christian and Ward [A-20] presents a summary of the way the data and concepts are incorporated into the overall framework of the MIT World Oil Model.

The NSF-sponsored work was concerned primarily with the concepts and methods of data collection and processing. The NSF funding did not provide for empirical work, and most of the actual estimation was funded by the U.S. Geological Survey and the Department of Energy under contract No. Ex-76-A-01-2295. The results of this work are utilized in the application by Smith and Paddock [A-17].

These improved data methods, and the updated empirical estimates, have been incorporated into the M.I.T. world oil simulation model, and have formed the basis for a series of presentations and papers by Jacoby and Paddock [A-13, A-14, A-15, A-16]. The updated supply model, with its interlinked set of analyses of demand and OPEC behavior, is used to define a universe of possible combinations of oil price and world economic conditions over the decade of the 1980s. The resulting "window"

of not-unlikely oil prices is quite wide, stretching from \$26 to \$45 per barrel in 1990 (in 1982 prices).

In addition, this ongoing work on supply analysis has helped support a number of analyses of world oil market issues, written by M.A. Adelman [A-1 through A-10].

Task 2 Integration of Supply Model and Financial Analysis

Subtask 2.1 Country Macrofinancial Model Development

The main purpose of this task was to modify our existing country financial model for linkage with the oil production model. The present structure of the financial model reflects well the general macro relationships in an oil-exporter's economy. The primary focus of this structure is the finance sector, including both domestic and foreign aspects. There are equations describing the money base and domestic credit supply, central bank activities, government budget financing, and international capital accounts. However, the flow of funds into and out of the oil sector are subsumed in the current level of aggregation, as is the effect of that sector on real output. Yet these are crucial elements of these countries' economies, and must be modeled explicitly to become subject to analysis.

Research was carried out on this question, with particular focus on methods for modeling the interaction of world capital markets and country macro-finance, within the context of our existing macro-financial model of Mexico. The conceptual framework for these interactions was investigated and initial model specification begun. Critical elements of these interactions were found to depend on institutional characteristics,

which are very difficult to model. Also, severe data constraints were encountered.

Subtask 2.2 Linkage of Oil Production and Macroeconomic Models

The focus of this subtask has been to develop initial approximations to a linkage mechanism for the two models described above in Subtasks 1.1 and 2.1. We have produced one publication bearing on this subject. It is entitled "Appropriate Financing for Petroleum Development in Developing Countries" by Agmon, Lessard and Paddock [A-12].

3. DISSEMINATION OF RESULTS

We have been involved in various activities that were included in the utilization plan of our proposal. The publication of research results during the period of the current grant is shown in Appendix A. Appendix B presents a list of meetings, testimony, speeches, conferences, and presentations by members of the Project over the period August 1980 through January 1983.

In addition, the MIT Center for Energy Policy Research (CEPR) sponsored four meetings which included sessions devoted to the world oil situation. The substantive 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. Appendix C contains the schedules of these meetings. For all these meetings there is an extensive discussion outline prepared beforehand. In the case of the November 1982 session, a more extensive analysis was written by Adelman and Neff [A-19], drawing on work from this NSF project.

All costs associated with these Conferences 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 project personnel 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. These meetings have involved groups of 40 to 80 people. Most of the organizations associated with the Center for Energy Policy Research have participated; this group includes many U.S. and foreign industries, several natural gas and electric utilities, several public interest organizations, a U.S. labor union, and several agencies of foreign governments. In addition, the meetings have included representatives of the U.S. Departments of Energy, Treasury, and State; the Council of Economic Advisers and the President's Inflation Adviser; the Office of Management and Budget; staff directors of Senate and House committees; officials from the Federal Reserve Bank and the International Monetary Fund; representatives from the banking and investment community; and scholars from other universities.

APPENDIX A

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
July 1980 through January 1983

PUBLICATIONS

1. Adelman, M.A., "Oil in the Eighties," Petroleum Economist, October, 1980.

Demand will continue weak throughout the 1980s. The OPEC countries will have considerable difficulty in deepening their cohesion, but the odds favor them.

2. Adelman M.A., "Energy Markets in the 1980s with Special Attention to Oil and How to Cope with Them: The Price of Energy with Special Attention to Oil," Ciclo De Conferencias Sobre Economia, Energeticos Y Desarrollo-Compendio, Three Lectures, Institute Mexicano del Petroleo, Mexico, D.E., October 28-39, 1980.

A series of discussions on the world oil market issues of the 1980s. The focus is on the prospects for the price of oil. Suggestions are made for how various market participants should cope with these issues.

3. Adelman, M.A., "The Realities of the Energy Market, an Agenda for the 1980s: Decisions and Research," in International Energy Options: Agenda for 1980s, ed. Paul Tempest, Oelgeschlager, Gunn and Hain Inc., Cambridge MA, 1980.

The higher energy prices of 1973 and of 1979 act like a glacial drift--imperceptible in the short run and irresistible in the long run--because they require long term investment, which incidentally is a drag on productivity and economic growth. Relative to national incomes, energy consumption will keep declining for many years.

Econometric supply analysis has, unlike that of demand, been unsuccessful. We have been unable to model the geological-investment interaction. And monopolized markets are intricate and even perverse. High prices and revenues support ever-higher prices.

Economic research is much needed, and "I would trade all the prognostications about the next century for a little understanding of this decade."

4. Adelman, M.A., "Testimony Before U.S. Senate Committee on Banking, Housing and Urban Affairs," mimeograph, January 1981.

The world oil market is one big pool, and special deals and special relationships are a harmful illusion. Prices may continue to trend upward, but they will be unstable in any case. Security will continue as a very serious problem, and only a stockpile can mitigate it.

5. Adelman, M.A., "Oil and the Energy Problem," University of Massachusetts, Business and Economic Report, Vol. 3, No. 3, Winter 1981.

Brief popular account: "Ever since the human race came down from the trees, it has been moving from one mix of energy sources to another, depending on which has cost the least." The latest move, or lurch, has been caused by the world oil monopoly, which will not soon disappear.

6. Adelman, M.A., "Coping with Supply Insecurity," The Energy Journal, Vol. 3, No. 2, March 1982.

An oil glut does not prevent disruption; it promoted one. But since World War II, some disruptions have had only negligible effects; some have been devastating. Supply crises are a demand phenomenon. The costs of physical dearth are so great that uncertain oil will be pursued at extravagant prices. There is an abrupt surge of demand for hoarding (sudden rightward shift of the short-run demand curve), which in the face of rigidly predetermined cartel supply, makes prices explode. The only remedy is in a large Strategic Petroleum Reserve, whose operating rule ought to be: keep the sales window open at all times, oil available at a penalty price which is a bargain when, and only when, dearth is feared. For great emergencies, a six-month stockpile is needed, to permit private and public decisions free of panic.

7. Adelman, M.A., "OPEC as a Cartel," in Griffin and Teece (eds.), OPEC Behavior and World Oil Prices, Allen and Unwin, 1982.

OPEC is a loosely cooperating oligopoly, or cartel, fluctuating between two basic modes: a residual monopoly by Saudi Arabia and other Gulf producers, with others producing freely, and an effective collusive group. The first is easy to maintain, but less rewarding than the second, hence continual oscillation, namde more difficult by non-identical interests among sellers, and more complex by ignorance of basic parameters: demand and non-cartel supply. Non-wealth-maximizing models of OPEC are logically defective and contrary to historical fact. The cartel may have already reached or surpassed its optimum price level. Consumption has responded strongly to price, but lower demand has not brought stability--the 1978 glut was the direct cause of the 1979 panic and price explosion. Instability and insecure supply will continue.

8. Adelman, M.A., "The Multinationals in the World Market in the 1970s and 1980s," paper at Fourth Annual Middlebury Conference on Economic Issues, forthcoming in volume edited by Charles P. Kindleberger, 1982.

The multinationals formed a highly concentrated integrated market structure which originated before World War I, and perpetuated itself because there were no strong economies, nor diseconomies of scale and integration. But refiners did not care to be exploited by the few producers, nor did producers relish selling to the few refiners. The cartel was a loose but effective grouping, though the Acnacarry agreement of 1928 was less an achievement than an acknowledgment of the difficulties of collusion. Contrary to stubborn legend, the cartel disappeared in World War II, and was never revived, although the companies managed that most difficult of military maneuvers, an orderly retreat from the higher price level. The price decline stung the producing-country governments to form OPEC and the greatest monopoly in history.

9. Adelman, M.A., "The Changing Structure of the Oil and Gas Market," in P. Tempest (ed.), International Energy Markets, Oelgeschlager, Gunn and Hain, 1983.

It is as yet impossible to speak of any worldwide market in natural gas, or even a domestic market in the U.S., because even a homogeneous product like natural gas sells at prices varying by a factor of five, allowance made for location. Nor does the price of gas stand in any rational relationship to the prices of competing fuels. The reason is price regulation in the U.S., and

non-recognition elsewhere of the non-premium nature of natural gas. Buyers are misled by irrational notions of quantitative "needs" not supply and demand, as well as vague political aims. Hence gross overpayment for Algerian gas; the Soviet gas deal is better, or less bad. The oil market continues in turmoil despite the great excess demand.

10. Adelman, M.A., "Oil Prices: The Protagonists," paper at Memorial for Enrico Mattei, Rome, October 1982 (to be published by Ente Nazionale Idrocarburi, 1983).

The principal protagonists used to be the multinational oil companies, long since reduced to the status of contractors or agents by the producing companies. The market is controlled, clumsily but very effectively, by the OPEC nations. The consumer-country governments occasionally take some ineffective measures, or make gestures, but their role can be neglected in trying to understand the market.

11. Adelman, M.A., and G. Ward, "Estimation of Worldwide Production Costs for Oil and Gas," 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 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.

12. Agmon, T., D.R. Lessard and J.L. Paddock, "Appropriate Financing for Petroleum Development in Developing Countries," originally M.I.T. Energy Laboratory Working Paper No. MIT-EL 81-059WP, September 1981, forthcoming in The Energy Journal.

The importance of international finance in energy investment by developing countries is clear. Financing may be the dominant factor determining that investment when enterprises or governments are constrained in their financing options, and hence are unable to fully shift risks or match income and expenditure streams.

This paper explores one important situation where financing constraints are likely to be binding--that of oil field development by capital-poor developing countries. Our primary analytic focus is those countries which, through foreign borrowing, have the potential to become significant net oil-exporters and for which oil represents a significant portion of their national wealth. We suggest financial instruments and policy interventions that may relax these constraints.

13. Jacoby, H.D. and J.L. Paddock, "Combining Analytical Models and Judgement in Oil Price Forecasts," Proceedings of the American Statistical Association (Business and Economics Statistics Section), American Statistical Association, Washington D.C., 1981.

A shortened, preliminary, version of material ultimately presented in "World Oil Prices and Economic Growth in the 1980s."

14. Jacoby, H.D. and J.L. Paddock, "World Oil Prices and Economic Growth in the 1980s," The Energy Journal, Vol. 4, No. 2, April 1983.

A set of interlinked models of world oil supply, demand and market behavior is used to develop an analysis of future world oil prices and economic growth. In exercises of this type, results often involve single-line forecasts of price, perhaps with some range of values calculated using alternative values of key parameters. In the case of the oil market, however, the uncertainty is so great that analytical models need to be used in a way that allows easy input of expert judgment and that fully reflects the range of possible outcomes.

The technique used here is to define a universe of possible combinations of oil price and world economic conditions over the decade of the 1980s, and then to use analytical models and judgment to define the set of points, G, that can be shown to be unlikely to occur. The complement of this set, G', then defines a "window" of oil price and growth patterns which are not-unlikely, and this result is offered as a way of stating the existing level of knowledge, and ignorance, about likely future developments in oil markets.

15. Jacoby, H.D. and J.L. Paddock, "Establishing an Oil Price Window: The Influence of 'Policy' on Future Oil Prices," in P. Tempest

(ed.), International Energy Markets, Oelgeschlager, Gunn and Hain, 1983.

Based on the research findings of "World Oil Prices and Economic Growth in the 1980s," this analysis leads to an argument that the dimensions of the oil price window are hard to influence by policy, but that governments do have means to influence the processes that tend to push the system toward the less-preferred regions of the window. An important focus of policy attention, then, should be on the response to supply disruptions, with an important instrument being the use of a portion of strategic stocks for price stabilization.

16. Jacoby, H.D. and J.L. Paddock, "Analysis of Oil Price and Economic Growth Through 1990," Proceedings of the Stanford University International Energy Workshop (December 1981), Stanford University, 1981.

This paper presents a summary of MIT World Oil Project models and their forecasting methodology. An illustrative forecast of oil prices is presented and contrasted with other approaches.

17. Smith, J.L., and J.L. Paddock, "Regional Modeling of Oil Discovery and Production," M.I.T. Energy Laboratory Working Paper No. MIT-EL 82-048WP, September 1982, forthcoming in Energy Economics.

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 production at the field level. The analytical framework is divided into two stages. First, the discovery analysis describes the physical returns to exploratory drilling (marginal expected field size), which provide additions to the potential reserve base. Second, the production analysis specifies the economic costs of bringing new fields on stream, and also describes the likely production rate.

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. In the production stage, production flow declines exponentially from the peak rate as the field is exhausted.

The paper contains new estimates of development cost functions that are sensitive to the physical characteristics of fields--including the size of fields, the rate of extraction, and the productivity of individual wells.

The analytical framework is illustrated by application to thirty-seven regions around the world.

18. Smith, J.L. and G.L. Ward, "Maximum Likelihood Estimates of the Size Distribution of North Sea Oil Deposits," Proceedings of the American Statistical Association, August 1980, and forthcoming in Journal of the International Association of Mathematical Geologists, 1982.

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, 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.

WORKING PAPERS

19. Adelman, M.A., and T.L. Neff (with M. Lynch and G. Ward), "International Oil Market Analysis," October 13, 1982.

This analysis represents an effort to put near-term developments in international oil markets into a context of longer-term trends. It includes a discussion of recent trends in world oil markets, and selected supporting data. In particular, demand trends and structural changes in the international market are examined. This examination seeks to provide some degree of critical assessment and to avoid the recurrently evident danger of extrapolating from near-term experience to significant long-term changes. Such extrapolations have proven costly for consumers and oil industries alike.

20. Carson, J., W. Christian, and G. Ward, "The MIT World Oil Model: Documentation and Use," MIT-EL 81-027WP, December 1981.

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.

21. Paddock, J.L., D. Seigel and J. Smith, "Claims on Physical Assets: The Case of Option Valuation of Offshore Petroleum Leases," M.I.T. Energy Laboratory Working Paper No. MIT-EL 83-005WP, February 1983.

This paper extends financial option theory by developing a methodology for the valuation of claims on a physical asset: an offshore petroleum lease. The advantages of this approach over conventional discounted cash flow techniques are emphasized. The methodological development provides important insights for both company behavior and government policy. Promising empirical results are reported.

22. Ward, G.L., "The Aggregate Supply Model: Documentation and Use," M.I.T. Energy Laboratory, Working Paper No. MIT-EL 81-038WP, June 1981.

This paper provides documentation of the Aggregate Supply Model, a computer-based model designed to forecast oil production capacity by producing region. The model is an inertial-process type model based on a few simplifying assumptions. These assumptions, plus key terms important for understanding the model, are described in this paper. Data requirements are identified and an example of results from a model simulation is presented. In addition, a technical description of both the model and the data is presented, along with a description of the computer code that implements the model.

BOOK REVIEWS

23. J.L. Paddock, Oil, Debt and Development, by P. Hallwood and S. Sinclair, in The Energy Journal, Vol. 3, No. 2, April 1982.
24. J.L. Paddock, The Oil Market in the 1980s: OPEC Oil Policy and Economic Development, by D. Aperjis, in Technology Review, April 1983.

APPENDIX B

List of Meetings, Conferences, Lectures, and Testimony by Project Personnel For the period of July 1980 through January 1983.

M.A. Adelman

July 1980	Conference at CIA (Washington) on oil and energy situation.
September 1980	Lecture at Southern Center for International Studies (Atlanta) on energy situation in U.S. and abroad.
October 1980	Lecture at Western Michigan University (Kalamazoo) on world petroleum.
October 1980	Lectures on energy prices and markets in the 1980s, with special attention to oil. Presented at the Instituto Mexicano Del Petroleo, Mexico.
October 1980 to November 1981	President, International Association of Energy Economists.
November 1980	Speaker at Energy Security Conference Yale University, New Haven, Connecticut.
December 1980 to January 1981	Consultant to U.S. Federal Trade Commission on international oil markets.
January 1981	Testimony on international energy/oil situation before U.S. Senate Committee on Banking, Housing, and Urban Affairs.
February 1981	Participant in panel on energy conditions today and tasks for the future at "History of the U.S. Energy Policy" symposium held at the Lyndon Baines Johnson Library, Austin, Texas.
April 1981	Lectures on world oil supply and demand, Northwestern University Transportation Research Center.
May 1981	Presented talk on OPEC as a cartel at "The Future of OPEC and the Long Run Price of Oil" conference held at the University of Houston, Houston, Texas.
May to July 1981	Consultant to U.S. Department of Justice on international oil markets.

- July 1981 Presented a paper on "North Sea Oil and Gas in the World Market: Perspectives on 1981-2000" at the Center for Policy Studies, London, England.
- November 1981 Presidential address at the IAEE Conference, Houston, Texas. Subject: security of oil supply.
- January 1982 Site visit to University of British Columbia to advise Canadian government grant body on a research project at U.B.C.
- April 1982 Lecture at Middlebury College (Vermont) conference on multinational corporations.
- June 1982 Lecture at Columbia University (Arden House) on Canadian and Mexican oil and gas industries.
- October 1982 Lecture at Ente Nazionale Idrocarburi (ENI) headquarters, Rome, Italy, part of commemoration of Enrico Mattei.
- January 1983 Speaker at The Conference Board (N.Y.) on "Shifting Energy Priorities."
- February 1983 Speaker at Business Week conference (Washington) on energy policy.
- April 1983 Lecture at University of Surrey (England) conference on "The Energy 'Crisis'--Ten Years After."
- April 1983 Testimony, Vermont Economic Committee on natural gas policy: international aspects.
- April 1983 Lectures at Northwestern University on world oil supply, demand, and market structure.
- June 1983 Testimony, U.S. House of Representatives, Committee on Science & Technology, on models of energy supply-demand-price.

H.D. Jacoby

- July to
December 1980 Member of National Petroleum Council Committee to Prepare Study of Refinery Flexibility.
- September 1980 to
April 1981 Member of National Petroleum Council Committee on Emergency Preparedness, and of the Coordinating Subcommittee of the Council's study of this topic.
- January 1981 Speech on World energy issues, sponsored jointly by MIT Industrial Liaison Office and Keidomren (Council of Economic Organizations), Tokyo.

- January 1981 Speech to the MIT Alumni Council on "International Oil and U.S. Energy Security."
- January 1981 Participant in panel on energy conditions today and tasks for the future at "The History of the U.S. Energy Policy" symposium held at the Lyndon Baines Johnson Library, Austi, Texas.
- May 1981 Presentation on world energy issues to Annual Conference Diversified Business Division, Aetna Life and Casualty Co.
- May 1981 Presented talk on OPEC as a cartel at "The Future of OPEC and Long Run Price of Oil" conference held at the University of Houston, Houston, Texas.
- June 1981 Participant in Energy Security Workshop sponsored by Harvard Kennedy School of Government and Center for Science and International Affairs.
- July 1981 Presented a paper on "North Sea Oil and Gas in the World Market: Perspectives in 1981-2000" at the Center for Policy Studies, London, England.
- November 1981 Speech on the security of oil supplies at the IAEE Conference, Houston, Texas.
- November 1981 Speech on world conditions to Israel Cultural Center, Boston.
- February 1982 Lecture on world oil developments to the S-128 group organized by the Institute for Gas Technology, Aspen, Colorado.
- June 1982 Presentation of paper to meeting of the International Association of Energy Economists, Cambridge, England.
- June to
December 1982 Member of National Petroleum Council Committee on Third World Petroleum Development.

James L. Paddock

- July 1980 Member of the Coordinating Subcommittee of the National Petroleum Council's "Study on U.S. Refinery Flexibility" attended meeting in Washington D.C.
- November 1980 Discussant at M.I.T. Center for Energy Policy Research meetings on World Oil Market Developments, Boston, Massachusetts.

- May 1981 M.I.T. Center for Energy Policy Research meetings. Rapporteur in sessions on future research in (1) energy and international finance; and (2) world oil supply, Cambridge, Massachusetts.
- May 1981 Speaker on world oil and international finance at meeting for economic and energy planners from South American countries. Sponsored by U.S Bureau of Labor Statistics, Cambridge, Massachusetts.
- June 1981 Meeting on world oil prospects with staff member of U.S. National Security Council, Cambridge, Massachusetts.
- September 1981 to May 1982 Organized and coordinated M.I.T. International Energy Studies weekly research seminar.
- December 1981 Speaker on world oil market prospects at Stanford University International Energy Workshop, Stanford, California.
- December 1981 Invited speaker on World Oil Price Forecasting and participant at Stanford University International Energy Workshop.
- January to May 1982 Faculty member of graduate level course entitled "Case Studies in Energy Technology, Economics and Management." This course drew heavily on material from M.I.T. World Oil Project.
- June to December 1982 National Petroleum Council: alternate member of Coordinating Sub-Committee for "Study on Third World Petroleum Development."
- October 1982 Invited speaker on World Oil Market Structure and Price Forecasting at Boston Architectural Commission.
- December 1982 Invited speaker on Financial Option Valuation of U.S. Offshore Oil Leases at American Finance Association Convention.
- Geoffrey Ward
- August 1980 Presented a paper on applying a statistical model for estimation of undiscovered oil reserves at the Business and Economic Statistics Section of the American Statistical Association, Houston, Texas.

APPENDIX C

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

Attached are meeting schedules for conferences on the world oil market. All costs of these conferences were paid by the M.I.T. Center for Energy Policy Research (CEPR). 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.

CEPR Meetings:

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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

AGENDA

CENTER ASSOCIATES PLANNING MEETING

May 20-21, 1981

Hyatt Regency, Cambridge

May 20, 1981 (Wednesday)

- 6:00 - 7:00 p.m. Cocktails
 *William Dawes Room
- 7:00 - 8:00 p.m. Dinner
 *Thomas Paine Room
- 8:00 - 10:00 p.m. "The Congressional Energy Agenda - 97th Congress"
 ● Frank Potter, House Committee on Energy &
 Commerce
 *Thomas Paine Room

May 21, 1981 (Thursday)

- 7:00 - 8:00 a.m. Breakfast
 *Empress Room (14th Floor)
- 8:00 - 9:30 a.m. Review of CEPR Sponsored Research
 *Thomas Paine Room
- 9:30 - 10:00 a.m. Coffee Break
- 10:00 - 12:00 Noon Panel Discussion Groups on Two Areas of CEPR
 Focus
 ● International Energy Markets
 ● Domestic Energy Policy, especially
 Synthetic Fuels
- 12:00 - 1:00 p.m. Lunch
 *Empress Room (14th Floor)
- 1:00 - 2:15 p.m. Reconvene as One Group to Report on Morning
 Discussion Groups
 *Thomas Paine Room
- 2:15 - 3:30 p.m. Discussion of Changed Policy Landscape
- 3:30 p.m. Adjourn

CEPR Meeting: March 1982

SCHEDULE

MARCH 11 - WORLD OIL SESSION

1:00 - 2:45 p.m.
(Haym Saloman Room)

Recent Market Events: Interpretation
of the Available Evidence

Presentation

Comments

Moderator

Morris Adelman

Richard Toohey

Loren Cox

2:45 - 3:15 p.m.

COFFEE

3:15 - 5:00 p.m.

Likely Developments in the Near to
Medium-Term Future

Presentation

Comments

Moderator

Henry Jacoby

Hugh Norton
Edward Morse

Loren Cox

5:00 - 6:00 p.m.
(MIT Prefunction Area)

REGISTRATION

CEPR Meeting: November 1982
SCHEDULE

October 31, 1982

- 6:00 - 7:00 p.m. COCKTAILS (Charles River Suite A)
 7:00 - 8:00 p.m. DINNER

REVIEW OF WORLD OIL MARKET SITUATION (Materials to Follow)

- 8:00 - 10:00 p.m. 1. Trends in Demand, Inventories and Consumption
 2. Changes in International Markets

November 1, 1982

- 7:30 - 8:30 a.m. BREAKFAST (Rib Room)

ELECTRIC POWER: REGULATION, DEREGULATION AND STRUCTURAL REFORM

- 8:30 - 9:30 a.m. 1. The Need for Reform (Charles River Suite A)
 Paul L. Joskow, M.I.T.
 Peter Navarro, Harvard
- 9:30 - 10:45 a.m. 2. Regulatory Reform: Inflation, Uncertainty and Efficiency
 Stewart Myers, M.I.T.
 Martin Zimmerman, M.I.T.
 Ernst Berndt and David Wood, M.I.T.
- 10:45 - 11:00 a.m. COFFEE
- 11:00 - 12:15 p.m. 3. Adapting to Regulatory Constraints and Regulatory Reform: Utility and Consumer Perspectives
 Guy Nichols, New England Electric System
 Richard Balzhiser, Electric Power Research Institute
 Jay Kennedy, Electricity Consumers Resource Council
 John A. Tillinghast, Wheelabrator-Frye
- 12:30 - 1:30 p.m. LUNCH (Charles Bar)
- 1:30 - 2:45 p.m. 4. Deregulation as an Alternative
 Fred Schweppe, M.I.T.
 William Berry, Virginia Electric Power Company
 Richard Schmalensee, M.I.T.
- 2:45 - 5:00 p.m. 5. Federal and State Government Responses
 Hunter Chiles, Department of Energy
 John Bryson, California Public Utilities Commission
 David Hughes, Federal Energy Regulatory Commission
 Richard Bower, Amos Tuck School of Business, Dartmouth
 (formerly Commissioner, New York State
 Public Service Commission)
- 5:00 - 6:00 p.m. COCKTAILS AND INFORMAL DISCUSSION

APPENDIX D

Cartel Behavior and Exhaustible Resource Supply: A Case Study of the World Oil Market

Publications and Working Papers for the Full Period of NSF Support
March 1975 through January 1983

PUBLICATIONS

1. Adelman, M.A., "Oil and the Energy Problem," University of Massachusetts, Business and Economic Report, Vol. 3, No. 3, Winter 1981.

Brief popular account: "Ever since the human race came down from the trees, it has been moving from one mix of energy sources to another, depending on which has cost the least." The latest move, or lurch, has been caused by the world oil monopoly, which will not soon disappear.

2. Adelman, M.A., "Coping with Supply Insecurity," The Energy Journal, Vol. 3, No. 2, March 1982.

An oil glut does not prevent disruption; it promoted one. But since World War II, some disruptions have had only negligible effects; some have been devastating. Supply crises are a demand phenomenon. The costs of physical dearth are so great that uncertain oil will be pursued at extravagant prices. There is an abrupt surge of demand for hoarding (sudden rightward shift of the short-run demand curve), which in the face of rigidly predetermined cartel supply, makes prices explode. The only remedy is in a large Strategic Petroleum Reserve, whose operating rule ought to be: keep the sales window open at all times, oil available at a penalty price which is a bargain when, and only when, dearth is feared. For great emergencies, a six-month stockpile is needed, to permit private and public decisions free of panic.

3. Adelman, M.A., "OPEC as a Cartel," in Griffin and Teece, OPEC Behavior and World Oil Prices, Allen and Unwin, 1982.

OPEC is a loosely cooperating oligopoly, or cartel, fluctuating between two basic modes: a residual monopoly by Saudi Arabia

and other Gulf producers, with others producing freely, and an effective collusive group. The first is easy to maintain, but less rewarding than the second, hence continual oscillation, namde more difficult by non-identical interests among sellers, and more complex by ignorance of basic parameters: demand and non-cartel supply. Non-wealth-maximizing models of OPEC are logically defective and contrary to historical fact. The cartel may have already reached or surpassed its optimum price level. Consumption has responded strongly to price, but lower demand has not brought stability--the 1978 glut was the direct cause of the 1979 panic and price explosion. Instability and insecure supply will continue.

4. Adelman, M.A., "The Multinationals in the World Market in the 1970s and 1980s," paper at Fourth Annual Middlebury Conference on Economic Issues, forthcoming in volume edited by Charles P. Kindleberger, 1982.

The multinationals formed a highly concentrated integrated market structure which originated before World War I, and perpetuated itself because there were no strong economies, nor diseconomies of scale and integration. But refiners did not care to be exploited by the few producers, nor did producers relish selling to the few refiners. The cartel was a loose but effective grouping, though the Acnacarry agreement of 1928 was less an achievement than an acknowledgment of the difficulties of collusion. Contrary to stubborn legend, the cartel disappeared in World War II, and was never revived, although the companies managed that most difficult of military maneuvers, an orderly retreat from the higher price level. The price decline stung the producing-country governments to form OPEC and the greatest monopoly in history.

5. Adelman, M.A., "The Changing Structure of the Oil and Gas Market," in Tempest (ed.), International Energy Markets, Oeleschlager, Gunn and Hain, 1983.

It is as yet impossible to speak of any worldwide market in natural gas, or even a domestic market in the U.S., because even a homogeneous product like natural gas sells at prices varying by a factor of five, allowance made for location. Nor does the price of gas stand in any rational relationship to the prices of competing fuels. The reason is price regulation in the U.S., and non-recognition elsewhere of the non-premium nature of natural gas. Buyers are misled by irrational notions of quantitative "needs" not supply and demand, as well as vague political aims. Hence gross overpayment for Algerian gas; the Soviet gas deal is better, or less bad. The oil market continues in turmoil despite the great excess demand.

6. Adelman, M.A., "Oil Prices: The Protagonists," paper at Memorial for Enrico Mattei, Rome, October 1982 (to be published by Ente Nazionale Idrocarburi, 1983).

The principal protagonists used to be the multinational oil companies, long since reduced to the status of contractors or agents by the producing companies. The market is controlled, clumsily but very effectively, by the OPEC nations. The consumer-country governments occasionally take some ineffective measures, or make gestures, but their role can be neglected in trying to understand the market.

7. 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.

8. 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 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.

9. 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.

10. 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 prices 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 pricing gyrations, because the controllers fear to lose control. They will avoid the dangerous surplus of supply and so will keep prices under pressure.

11. Adelman, M.A., "Oil in the Eighties", Petroleum Economist, October, 1980.

Demand will continue weak throughout. The OPEC countries will have considerable difficulty in deepening their cohesion, but the odds favor them.

12. Adelman, M.A., "Energy Markets in the 1980's with Special Attention to Oil and How to Cope with Them: The Price of Energy with Special Attention to Oil, Ciclo De Conferencias Sobre Economia, Energeticos Y Desarrollo-Compendio, Three Lectures, Institute Mexicano del Petroleo, Mexico, D.E., October 28-30, 1980.

A series of discussions on the world oil market issues of the 1980s. The focus is on the prospects for the price of oil. Suggestions are made for how various market participants should cope with these issues.

13. Adelman, M.A., "The Realities of the Energy Market, an Agenda for the 1980's: Decisions and Research", in International Energy Options: Agenda for 1980's, Paul Tempest (ed.), Oetgeschlager, Gunn and Haïne Inc., Cambridge, MA, 1980.

The higher energy prices of 1973 and of 1979 act like a glacial drift--imperceptible in the short run and irresistible in the long run--because they require long term investment, which incidentally is a drag on productivity and economic growth. Relative to national incomes, energy consumption will keep declining for many years.

Econometric supply analysis has, unlike demand, been unsuccessful. We have been unable to model the geological-investment interactions. And monopolized markets are intricate and even perverse. High prices and revenues support ever-higher prices.

Economic reasearch is much needed, and "I would trade all the prognostications about the next century for a little understanding of this decade."

14. 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.

15. Adelman, M.A. and G. Ward, "Estimation of Worldwide, Production Costs for Oil and Gas", 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 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.

16. 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.

17. Agmon, T., D.R. Lessard, and J.L. Paddock, "Appropriate Financing for Petroleum Development in Developing Countries," originally M.I.T. Energy Laboratory Working Paper No. MIT-EL 81-059WP, September 1981, forthcoming in The Energy Journal.

The importance of international finance in energy investment by developing countries is clear. Financing may be the dominant factor determining that investment when enterprises or governments are constrained in their financing options, and hence are unable to fully shift risks or match income and expenditure streams.

This paper explores one important situation where financing constraints are likely to be binding--that of oil field development by capital-poor developing countries. Our primary analytic focus is those countries which, through foreign borrowing, have the potential to become significant net oil-exporters for which oil represents a significant portion of their national wealth. We suggest financial instruments and policy interventions that may relax these constraints.

18. 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.

19. 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.

20. 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.

21. 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.

22. 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.

23. 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.

24. 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.

25. 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.

26. 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.

27. 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.

28. 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.

29. Jacoby, H.D. and J.L. Paddock, "Combining Analytical Models and Judgement in Oil Price Forecasts," Proceedings of the American Statistical Association (Business and Economics Statistics Section), American Statistical Association, Washington D.C., 1981.

A shortened, preliminary, version of material ultimately presented in "World Oil Prices and Economic Growth in the 1980s."

30. 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 for U.S. policy are discussed.

31. Jacoby, H.D. and J.L. Paddock, "World Oil Prices and Economic Growth in the 1980s," The Energy Journal, Vol. 4, No. 2, April 1983.

A set of interlinked models of world oil supply, demand and market behavior is used to develop an analysis of future world oil prices and economic growth. In exercises of this type, results often involve single-line forecasts of price, perhaps with some range of values calculated using alternative values of key parameters. In the case of the oil market, however, the uncertainty is so great that analytical models need to be used in a way that allows easy input of expert judgment and that fully reflects the range of possible outcomes.

The technique used here is to define a universe of possible combinations of oil price and world economic conditions over the decade of the 1980s, and then to use analytical models and judgment to define the set of points, G, that can be shown to be unlikely to occur. The complement of this set, G', then defines a "window" of oil price and growth patterns which are not-unlikely, and this result is offered as a way of stating the existing level of knowledge, and ignorance, about likely future developments in oil markets.

32. Jacoby, H.D. and J.L. Paddock, "Establishing an Oil Price Window: The Influence of 'Policy' on Future Oil Prices," in P. Tempest (ed.), International Energy Markets, Oelgeschlager, Gunn and Hain, 1983.

Based on the research findings of "World Oil Prices and Economic Growth in the 1980s," this analysis leads to an argument that the dimensions of the oil price window are hard to influence by policy, but that governments do have means to influence the processes that tend to push the system toward the less-preferred regions of the window. An important focus of policy attention, then, should be on the response to supply disruptions, with an important instrument being the use of a portion of strategic stocks for price stabilization.

33. Jacoby, H.D. and J.L. Paddock, "Analysis of Oil Price and Economic Growth Through 1990," Proceedings of the Stanford University International Energy Workshop (December 1981), Stanford University, 1981.

This paper presents a summary of MIT World Oil Project models and their forecasting methodology. An illustrative forecast of oil prices is presented and contrasted with other approaches.

34. O'Carroll, F. and J.S. Smith, "Probabilistic Methods for Estimating 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.

35. Paddock, J.L., "World Oil Markets: MIT World Oil Project Outlook for the 1980s," in Proceedings of the American Institute of Chemical Engineers National Meetings: 1980, AIChE, New York, 1980.

Various analytic approaches for forecasting world oil prices and economic growth yield "reference" or point estimates. This paper points out the futility of point forecasts due to the great uncertainties involved in exercises of this type. The MIT World Oil Project Models are simulated to show the wide range of possible and consistent outcomes.

36. Paddock, J.L., "MIT World Oil Project Outlook," in World Energy Outlook, proceedings of the St. Louis University International Business Conference, St. Louis, 1970.

An analytic forecast of possible combinations of oil prices and economic growth for the world through 1990. The MIT World Oil Project Models are simulated and the results presented.

37. 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.

38. 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 producers from the cartelization of the world petroleum, copper and bauxite markets are calculated under the assumption of optimal dynamic monopoly pricing of an exhaustible resource. Small quantitative models for the markets for each resource are developed that 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.

39. 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 possibility 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.

40. 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.

41. 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.

42. 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.

43. 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.

44. 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.

45. 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.

46. 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.

47. 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.

48. 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 estimated using pooled data for nine countries. Other models, including the logit model, were also tested. Results from this study seem to indicate that price elasticities for energy demand are larger

than had been thought earlier. The own price elasticity for total energy demand was estimated to be about $-.9$.

49. 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.

50. Smith, J.L. and G.L. Ward, "Maximum Likelihood Estimates of the Size Distribution of North Sea Oil Deposits", Proceedings of the American Statistical Association, August 1980, and forthcoming in Journal of the International Association of Mathematical Geologists, 1982.

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.

51. Smith, J.L., and J.L. Paddock, "Regional Modeling of Oil Discovery and Production," M.I.T. Energy Laboratory Working Paper No. MIT-EL 82-048WP, September 1982, forthcoming in Energy Economics.

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 production at the field level. The analytical framework is divided into two stages. First, the discovery analysis describes the physical returns to exploratory drilling (marginal expected field size), which provide additions to the potential reserve base. Second, the production analysis specifies the economic costs of bringing new fields on stream, and also describes the likely production rate.

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. In the production stage, production flow declines exponentially from the peak rate as the field is exhausted.

The paper contains new estimates of development cost functions that are sensitive to the physical characteristics of fields--including the size of fields, the rate of extraction, and the productivity of individual wells.

The analytical framework is illustrated by application to thirty-seven regions around the world.

WORKING PAPERS AND REPORTS

52. 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.

53. 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.

54. Adelman, M.A., and T.L. Neff (with M. Lynch and G. Ward), "International Oil Market Analysis," October 13, 1982.

This analysis represents an effort to put near-term developments in international oil markets into a context of longer-term trends. It includes a discussion of recent trends in world oil markets, and selected supporting data. In particular, demand trends and structural changes in the international market are examined. This examination seeks to provide some degree of critical assessment and to avoid the recurrently evident danger of extrapolating from near-term experience to significant long-term changes. Such extrapolations have proven costly for consumers and oil industries alike.

55. 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.

56. 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.

57. Agmon, T., D. R. Lessard and J.L. Paddock, "Accommodation in International Capital Markets: Paying for Oil, Financing Oil and the Recycling 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.

58. 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.

59. 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.

60. 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.

61. Carson, J., W. Christian, and G. Ward, "The MIT World Oil Model: Documentation and Use", MIT-EL 81-027WP, December 1981.

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.

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

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).

63. 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.

64. 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 countries. Most of these countries have experienced severe inflation and economic disparities since 1974. A better understanding of the role of oil revenues on the domestic economy of these countries can provide useful guidelines for better management of these economies and as a result provide more stability in the world oil market.

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.

65. 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.

66. 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.

67. 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.

68. 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.

69. 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.

70. 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.

71. 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.

72. 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.

73. Paddock, J.L., D. Seigel and J. Smith, "Claims on Physical Assets: The Case of Option Valuation of Offshore Petroleum Leases," M.I.T. Energy Laboratory Working Paper No. MIT-EL 83-005WP, February 1983.

This paper extends financial option theory by developing a methodology for the valuation of claims on a physical asset: an offshore petroleum lease. The advantages of this approach over conventional discounted cash flow techniques are emphasized. The methodological development provides important insights for both company behavior and government policy. Promising empirical results are reported.

74. 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 reservoir 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.

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

75. Ward, G.L., "The Aggregate Supply Model: Documentation and Use," M.I.T. Energy Laboratory, Working Paper No. MIT-EL 81-038WP, June 1981.

This paper provides documentation of the Aggregate Supply Model, a computer-based model designed to forecast oil production capacity by producing region. The model is an inertial-process type model based on a few simplifying assumptions. These assumptions, plus key terms important for understanding the model, are described in this paper. Data requirements are identified and an example of results from a model simulation is presented. In addition, a technical description of both the model and the data is presented, along with a description of the computer code that implements the model.