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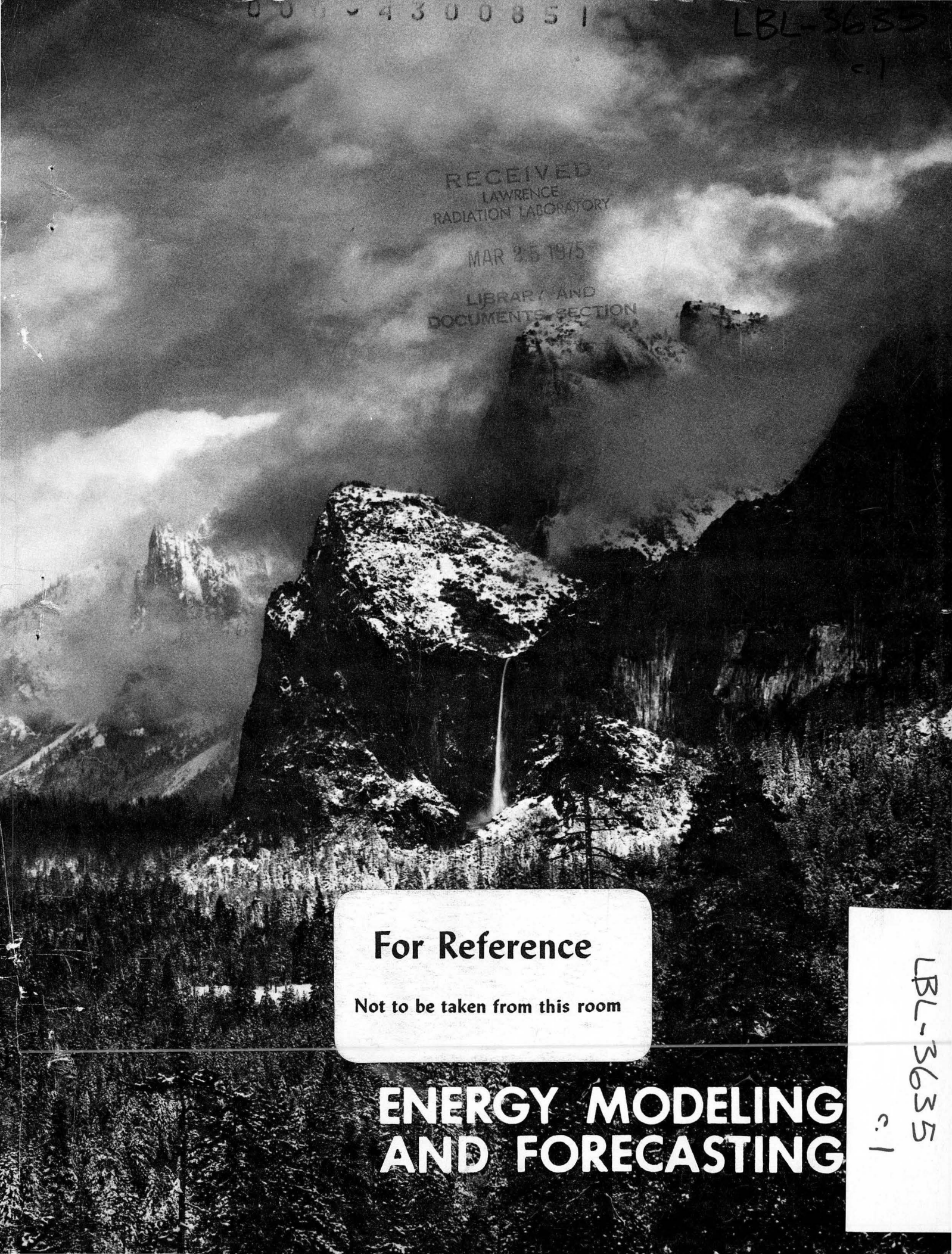

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ENERGY MODELING AND FORECASTING

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PROCEEDINGS
of the
CONFERENCE ON
ENERGY MODELING AND FORECASTING

June 28, 29, 1974

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CONFERENCE OBJECTIVES

Last April Paul Craig of the Office of Energy R & D Policy at the National Science Foundation suggested that we hold a conference at the Lawrence Berkeley Laboratory on energy modeling and forecasting. The focus of the conference was methodological. The objectives were to evaluate the suitability of present modeling techniques for responding to energy policy questions, and to explore approaches for improving each method. We decided to assemble a small but diverse group of people working in energy modeling to bring out complementarities among the methods. The discussion component played a large part at the conference. Each participant was asked to address how the techniques he uses can be applied under today's circumstances. The discussions focused on the strengths and weaknesses of alternative methodologies. The participants were also asked to criticize their methods in terms of the assumptions of the model, the applicability of the model to today's conditions, the policy questions that can most easily be addressed, the time horizon of the model, the treatment of uncertainty, and the phenomena that can be most and least readily described. The conference was held on the 28th and 29th of June, 1974.

The first paper dealt with the relationship of methods to policy questions. Most of the remaining papers dealt with particular methods, including probability theory, network analysis, linear programming, regression analysis, input-output, process analysis, systems dynamics, interactive game theory, and computer simulation techniques. The final presentations, which focused on energy models from a user's point of view, were made by representatives from an oil company and from a public utilities company.

The results of the conference were, first, an exposition of a variety of modeling methods and their applications to particular problems. This material is presented at two levels of detail: 1) a summary of each paper was prepared after the conference; 2) the full text of each paper is reprinted. Second, there were several general topics which arose from the formal presentations and the discussions following them. They are described in some detail in the Summary of Results, and are expanded more thoroughly in the summaries of the papers and discussions, the discussion transcripts, and the papers. The reader may find it helpful to read the Summary of Results and the summaries of each paper and discussion first. This material was written after the conference. It is designed to help the reader determine which papers and discussions are closest to his particular interests.

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SUMMARY OF RESULTS

The main ideas which arose from the formal presentations and the discussions accompanying them centered around the following topics: 1. definition of the policy question; 2. criteria for model choice; 3. model validation; 4. data problems; 5. methods for improving models and directions for additional research; 6. interaction between policy maker and modeler; and 7. methodological criticisms of the models. They are treated in this order below, though comments on each of these topics arose at various points throughout the conference.

DEFINITION OF THE POLICY QUESTION

The model builder needs to define the policy question in order to decide what kind of detail to build into the model to make it useful. The policy maker must know what kind of policy question he has to answer in order to determine what type of model would be suitable for answering it. We determined that both high and low forecasts may be used to answer different types of policy questions. For example, in R & D planning, a high forecast may be appropriate. One does not want to foreclose the options of new energy technologies by foregoing R & D, since the expenditures for R & D are small relative to those that will subsequently be needed for capital investment to implement the research and development results. On the other hand, one would want a much more precise forecast for making capital investment decisions, since the expenditures required are much larger, and the consequences of a wrong decision are greater. We also discussed the kinds of forecasts appropriate for resource allocation and for environmental legislation.

A conclusion which emerged several times is that there is no model appropriate for all purposes. Therefore an articulation of the policy question to be answered is mandatory. Accordingly, a model can be evaluated only in terms of its usefulness for responding to a particular type of policy question. Also relevant for this evaluation is the time frame in which the policy question applies, as we determined that some models are clearly appropriate for short-run analysis and others are applicable only in the long-run.

These ideas led to discussion of the self-fulfilling nature of energy projections. Whether projections are self-fulfilling or not depends on what is being projected and who is using the projection. We discussed this self-fulfilling property with respect to R & D policy, corporate investment policy, and the utilities as users of energy models.

CRITERIA FOR MODEL CHOICE

Once the policy question and a time frame have been established, the criteria for choosing a model come into play. From both the user's and the model builder's point of view, we were able to synthesize a list of considerations which should be taken into account. These are:

1) a theoretical structure that incorporates functional demand, that is, demand for a particular service, and not for a particular type of energy
2) the effect of price
3) the effect of technological change
4) fuel substitution possibilities
5) a scheme for data disaggregation that can conveniently be aggregated to summarize results
6) the constraints of the natural resource base
7) the treatment of environmental effects
8) accuracy
9) level of aggregation
10) time horizon
11) cost.

For regression models a more specific list of characteristics was developed. They are:

1) disaggregation by sector, region, and fuel type
2) the inclusion of price effects
3) attention to the theoretical structure of demand
4) a distinction between the capital stock of energy using equipment and the energy usage pattern.

Keeping these characteristics in mind, the model builder must tailor his method to the characteristics of the sector to be modeled and the data availability. From the discussions following each of the papers we were able to determine which of these characteristics are included in each of the models. We were also able to determine which subsets of these characteristics must be included in the model in order to render it useful for responding to different types of policy question. Thus we were able to pair policy questions with the appropriate model for responding to it.

MODEL VALIDATION

The choice of the model validation criteria depends upon the policy question to be answered. In some cases, such as the near-term allocation of oil, predictive accuracy is essential, so this becomes the criterion for evaluating the model. In other cases, one might be interested in differential impacts, either by

sector, by region, or by implementation of alternate policies. Therefore, the criterion becomes not predictive accuracy, but the ability of the model to register relative effects. If technolgical change is in question, one cannot rely on either of the above criteria; the subjective probability estimates of experts is required to validate the model. However, tests have shown that these are often inaccurate. Furthermore, the time scale over which the model is valid must be considered. Often models are compared to test their validity. If the models produce different results, one needs to know what assumptions, judgments, or degrees of conservatism produced these different effects before the question of model validation can be answered.

DATA PROBLEMS

Data problems arose in almost every discussion. On the supply side, especially in the case of natural resources, the main problem seems to be that either the data have not been collected or are proprietary. On the demand side, there are many gaps in the data, and usually the data that exists are not sufficiently disaggregated.

METHODS FOR IMPROVING MODELS

The discussion of methods for improving models revolved around making models more dynamic, combining models, taking into account short-run dislocations, and making use of various academic disciplines for estimating demand functions. To make models more dynamic, it was suggested that the following components be incorporated: price, interest rates, capital accumulation, technological change, changes in investment patterns, and the emergence of new lending institutions to finance capital formation. Methods were discussed for implementing some of these refinements. We determined which of the models have some of these components built into them presently, and which have the potential for incorporating them. For example, the Hudson-Jorgenson model accounts for price changes, and the Brookhaven model has a component for technological change.

From the discussion of the strengths and weaknesses of each of the models, the advantages of combining complementary models became evident. An example of a model that already incorporates two techniques is the Hudson-Jorgenson model which uses econometrics and input-output analysis. We discussed the possibility of incorporating the price-technology interaction of this model with the much greater level of sectoral disaggregation of the input-output model we are using at LBL. We also discussed the possibility of combining the technological detail of the Brookhaven model with both of these models. Other possible combinations include regional and national models, micro and macro models, and descriptive and optimization models. The purpose of combining models is to supplement the weakness of one with the strength of another. However, in doing so, the weakness of the second model is also introduced, and in fact, there may be a magnification of errors as the models are combined. Therefore, careful testing of a combined model is necessary in order to insure that something has been gained by making the combination.

The question of how to incorporate such drastic disturbances as the Arab oil embargo and the attendant change in prices was brought up. We concluded that none of the models discussed at this Conference can at present incorporate such a change. However, the econometric model outlined by Verleger which distinguishes between capital stock and energy usage patterns, and is disaggregated by sector, region, and fuel type, appears to be usable even if such disturbances take place. Prices would affect the utilization of fuel burning appliances and the demand would be appropriately reduced; supply limitations can also be accounted for.

Another suggestion for improving the energy models is to include people from the behavioral sciences in the formulation of demand functions. This is suggested because the demand for a particular good or service has strong sociological and psychological components.

INTERACTION BETWEEN POLICY MAKER AND MODELER

Clearly there is a need for two-way communication between model builders and policy makers but we found there appear to be obstacles hindering this. First, the two groups often have dissimilar backgrounds and training. Second, decision makers may be distrustful of models for several reasons:

1) the model structure or the results do not conform to the decision maker's prejudices
2) he may not understand the model and may feel threatened by its complexity
3) the results may not agree with historical data.

We also discussed the role of funding agencies as a third group which often stands between model builders and policy makers. Thus, in some cases there is no direct contact between the group building the model and the ultimate user. From the model builder's viewpoint, funding agencies appear to emphasize the funding of research which answers short-term crisis situations. If the state of the art of modeling is to improve, the funding of long-term research is also needed. Finally, it was brought out that the usefulness of models depends partly upon how well model builders an-

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ticipate problems that policy makers may not recognize, and also upon how well they then bring them to public attention before a crisis situation develops.

METHODOLOGICAL CRITICISMS OF THE MODELS

Numerous criticisms were made of each model in terms of the validity of the assumptions, the level of detail, the inclusion of key components, the theoretical structure, and the method by which each model was tested. These criticisms were made from the viewpoint not only of the model builder but also of those who use energy models. The criticisms appear in the summaries and throughout the conference transcripts. The main ones are listed below. Kaufman's probabilistic model of the oil and gas discovery process is limited by data availability and cannot easily be generalized to large geographical regions. But the model can be combined with another that uses data derived from subjective judgments of oil experts; with this modification, discovery may be predicted where no drilling has been done. The coupled energy system model being developed by Hoffman does not incorporate price effects. Hudson's econometric-input-output model is too highly aggregated; only nine sectors are distinguished. Also, the concept was tested using trend extrapolations, not real data. The econometric estimation of energy demand elasticities which Griffin made using international data does not distinguish between institutional differences across countries. Baughman's study of interfuel substitution in the consumption of energy does not make the stock-flow distinction. Furthermore, there is no regional detail. The interactive gaming model which Utsumi is building has not been completed. Several aspects of it remain unclear:

1) the type of policy question that can reliably be dealt with using this model
2) the methods by which the submodels are combined
3) whether errors are compounded by the use of a variety of modeling techniques.

Verleger's proposed econometric model to project energy demand has not been constructed; however, the approach appears reasonable.

ACKNOWLEDGMENTS

Many people helped with the organization of the conference and the publication of the proceedings. Paul Craig of the National Science Foundation suggested to me the idea of the conference. He helped to formulate the objectives and was instrumental in expediting the funding. Frank Alessio (Electric Power Research Institute), Ken Hoffman (Brookhaven National Laboratory), B. F. Roberts (University of California, Berkeley), Milton Searl (Electric Power Research Institute), and James Walker (Office of Management and Budget) served on the advisory panel. Together we decided upon the list of participants and the scope of methods that were discussed.

The participants at the conference gave their time generously to prepare papers, discuss modeling problems, and review portions of the proceedings before final printing. They made objective and constructive efforts to criticize their own work as well as each other's. Henry Ruderman continually exchanged ideas with me since I began working on the conference last Spring. Along with Deane Merrill, Jayant Sathaye, and Bob Budnitz, he shared with me the work of preparing the summaries of each paper and discussion session. They also helped me with the arduous taks of proofreading.

Ted Kirksey of the LBL Technical Information Department provided the overall supervision of the recording and publication process. Most importantly, he ensured that the multitude of tasks within these processes were carried out accurately and completely. Loretta Lizama supervised the composition, editing, comment-incorporation, and proofreading throughout the numerous iterations that were required. On this as well as on previous occasions, her careful management of this aspect of the project made the rest of work considerably easier. Bob Barton and Josephine Camp contributed technical editing on all phases of the manuscript. In the later stages of the publication, Bob Barton also helped coordinate the composition and layout of the final copy. Most of the final composition was done by Jacqueline Breland, Melba Sharp, and Arlene Spurlock. They also helped with typing of the preliminary copy, as did Patricia Cowper, June De LaVergne, Carmen Hubbard, Deborah Olson, and Marthamae Snyder.

Ansel Adams generously gave us permission to use his photograph "Clearing Winter Storm" (Yosemite National Park, California, 1944) on the cover of the proceedings.

The contribution of all these people is greatly appreciated.

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ENERGY PROJECTIONS—RELATIONSHIP TO POLICY ISSUES

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SUMMARY

Accuracy is not the only criterion for evaluating an energy projection. Other attributes of specific forecasts, such as scope, level of aggregation and time horizon should also be considered in light of the policy issue to be addressed. Even a rough approximation of the relative changes attributable to alternative policy actions may be more important than the accurate determination of the demand level.

It is not inconsistent for the same groups to use low or high forecasts depending upon the policy questions they are trying to answer. Because energy policy questions are related to social, economic, political, and environmental issues, energy models must be embedded in an overall framework or model that encompasses these issues. Different methods will provide different results. It is important to understand whether these differences reflect different economic and social assumptions, different judgments of the influence of the same assumptions, or different degrees of conservatism imposed by the policy issues addressed.

The factors influencing projections in the near, intermediate, and long term were also distinguished.

Four general policy questions were then presented and examined to indicate which attributes were most important and which ones did not need to be stressed. The four policy questions are: research and development planning, capital investment, near-term allocation of oil, and the regulation of rates and environmental standards.

* * *

INTRODUCTION

The supply of and demands for energy in various forms clearly depend on such factors as geology, population, income, energy price, and lifestyle. The more sophisticated energy projections are generally based on forecasts involving these causal parameters. The relatively constant growth rate that has held in the past for electrical energy as well as for total energy demand has made the art of energy forecasting seem like quite a simple task. Under these circumstances it is no surprise that linear extrapolations or simple regression analyses have proven to be the most reliable methodologies for projecting aggregate energy demands. Indeed, those who attempted to disaggregate energy demands and to treat the causal factors behind energy demands in more detail were generally rewarded with failure in the form of a less accurate forecast. In view of the tremendous expansion of activity in energy planning and analysis, and the changing economic and environmental framework that is operating, it is timely to reassess the forecasting or projection methodologies that are employed and, in particular, to examine the types of projections that are required to address specific policy issues. Other papers in this conference will address the methodological issues, hence the balance of this paper will deal with the latter question. Throughout this paper the terms energy supply and energy demand may be used interchangeably on the basis that over any reasonable interval of time supply equals demand. The situation at any given time can, however, be supply or demand constrained.

BASIC ISSUES

A general impression that appears to be prevalent is that better, implying more accurate, forecasts are required before policy formulation may be attempted. Given the fact that the future is essentially unknowable it is probable that increased sophistication in methodologies with the single objective of improved accuracy is inappropriate and counterproductive. In particular, as increased attention is given to detail and treatment of causal effects, the uncertainties increase. The interest of this paper is to focus attention on the question of uncertainty and the trade-offs between accuracy, detail, and other attributes of demand projections that must be made explicit as methodologies of increased sophistication are developed and applied to energy policy analysis. There is no excuse for sloppy projections but it must be recognized that policies will continue to be developed on the basis of imperfect forecasts.

Disregarding projections made to win bets or establish one's reputation as a seer, projection of future energy demands, over the near and long term and at various levels of detail, are developed to provide the basis for some policy action such as the establishment of oil import quotas, the determination of rates for peak electric demands, investment in refineries and power plants, and investment in research and development options. It must be recognized that such attributes of specific forecasts such as scope, format, level of aggregation, and time horizon are strongly dependent on the policy issue to be addressed. With regard to the total energy demand, for example, the projections may be viewed as a band of possible demand levels increasing in width over time. This is shown in Figure 1. Subjective probability statements may be made for given demand levels at future dates and the

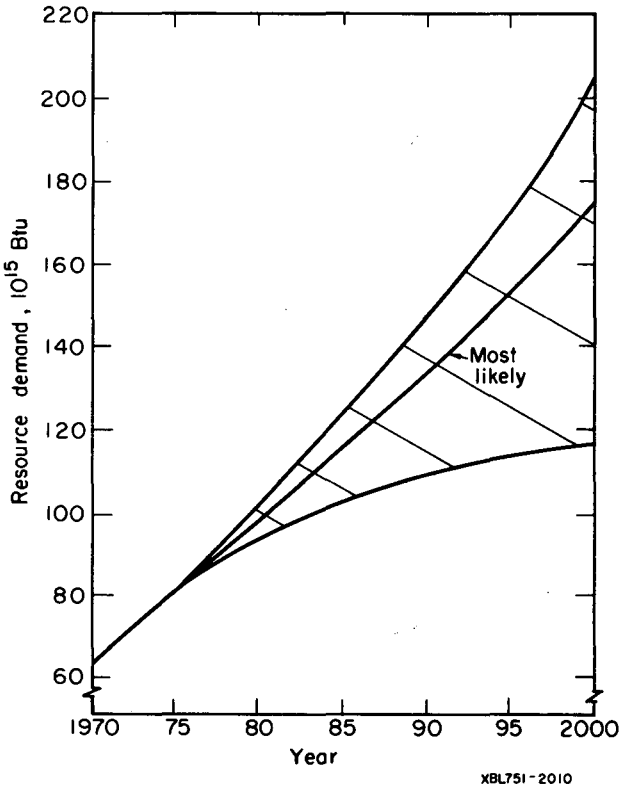

Fig. 1. Distribution of energy resource demand projections to the year 2000.

implications of such levels with respect to capital requirements, emissions of pollutants, and power plant sites may be determined with a fairly high degree of accuracy. Clearly the level of such detail to which a projection or range of projections is developed depends on the policy issue to be addressed. What is not as clear is the fact that it is entirely consistent for individual groups to select different projections from this distribution, depending on the degree of conservatism or optimism they wish to reflect as the basis for policy.

It may be argued that one of the higher projections should be used as the basis for a research and development strategy while a mean range, or most probable, projection should be used as the basis for capital investment. A low range projection may be preferred if the intent is to try to influence prices in world trade markets.

Because many of the important energy policy questions deal with the interrelationships of energy with the economy, society, and the environment, models used for energy projections must be embedded in models or scenarios of social and economic development and the physical environment. This embedding will require a broad spectrum of sophisticated analytical tools of the type to be discussed at this conference. It seems likely that each of the methodologies to be discussed will have its particular role and strength and it would be useful for the discussion to focus on these attributes as well as on the prospect for identifying the reasons behind the differences between forecasts developed by various methodologies. Do these differences reflect different economic and social assumptions, different judgments of the influence of a consistent set of basic assumptions, or different degrees of conservatism imposed by the policy issues addressed. It is likely that all of these factors and others are operating and it would be useful to try to focus on these questions.

Many researchers ask "How may energy projections be validated?" This question requires careful consideration. Accuracy in an absolute sense cannot really be allowed to be the most important criterion else policy analysis will never move far beyond meetings of this type. Linear extrapolations have proven to be extremely accurate in the past but do not provide any insight into the causal factors and role of policy variables. A more sophisticated model, though perhaps less accurate, is more useful if it adequately reflects variations in demand attributable to changes in policy variables. In many policy applications even rough analysis of the relative changes attributed to alternative policy actions may be more important than the accurate determination of demand level. Still another problem to be faced in validation is that a methodology that has failed in the past may still be valid for future projections as conditions change.

A projection published by Resources for the Future in 1963 [1] has been subjected to careful evaluation to determine why the projected 1970 demand differed from the actual demand.[2] This projection was

based on detailed evaluation of saturation effects and technological change in all end uses of energy. A departure from exponential growth was projected and the authors admitted that they would have done better with a linear extrapolation on semi-log paper. Nevertheless, the analysis of this projection after the fact provided considerable insight into the many factors that led to continuation of the constant growth rate over that period. To my knowledge this was the only projection made at that time in which the reason for the errors could possibly be identified.

It is also well to keep in mind a viewpoint perhaps expressed best by Herbert Simon[3]. Dr. Simon proposes that the uncertainty in energy projections to some future point in time be looked on as an uncertainty in the time at which a given demand level is reached rather than in the level of demand at a specific point in time. He proposes that policy be based on a situation where the demand for energy will be, say, three times current demand without worrying about whether that level is actually reached in the year 1993 or 2005. Referring to the range of projections summarized in Figure 2 it is apparent that the levels projected for the year 2000 vary by about 25% from the lowest to the highest. This uncertainty seems less critical when it is viewed as the uncertainty whether the demand level of 160×10^{15} Btu will be reached as early as the year 1991 or as late as 2000. This time uncertainty decreases of course as one proceeds in the direction of near term projections.

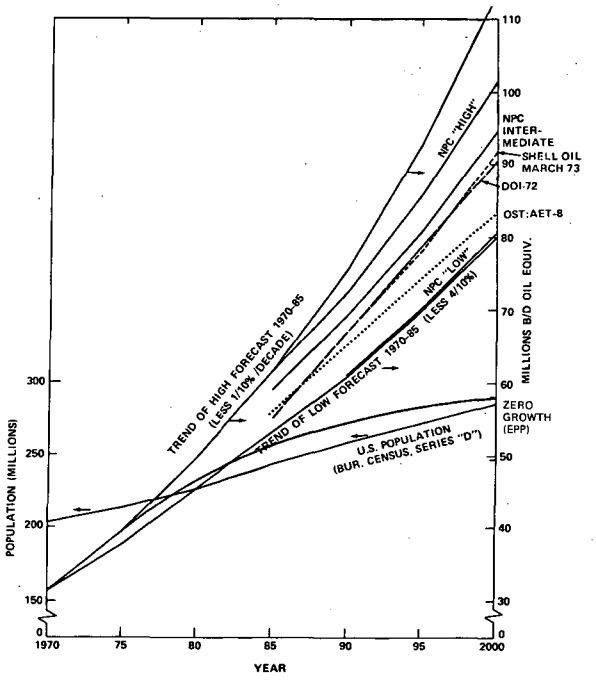

Fig. 2. Summary of projections to the year 2000. (Source: Understanding the National Energy Dilemma, Joint Committee Print, JACE, 1973).

Following is a more detailed and ordered discussion of several of the issues that have been raised. The complete list of issues addressed above is given in Table I.

POLICY ISSUES AND PROJECTION ATTRIBUTES

There are a variety of attributes that may be used to characterize energy projections and they are not independent. More aggregated projections, for example, have in the past been more accurate, but less useful from the policy viewpoint than projections incorporating increased supply and demand detail. Following is a partial list of attributes of energy projections.

1. Accuracy; relative and absolute
2. Geography; regional, national, world
3. Scope; single fuel (e.g., natural gas) single energy form (e.g., electricity), all energy forms, or some combination.
4. Level of aggregation of demands; sectors such as residential, commercial, etc., or detailed end uses such as space heat and aircraft demands
5. Time horizon; near term 1 to 5 years, intermediate term 5 to 20 years, or long term beyond 20 years.
6. Identification and parametrization of causal factors such as population, income, price, technological change, weather and life style.

For the purposes of stimulating discussion, a number of policy issues are discussed below. In all of these issues, energy projections are an important piece of information on which the selection of policy actions will be based.

RESEARCH AND DEVELOPMENT PLANNING

Long range projections are required with a great deal of technological detail. Accuracy is not an important criterion and conservatism is warranted in the form of using a high projection as the planning basis. This introduces the spectre of the "self-fulfilling prophecy" which is felt to be overrated in any case but clearly is less at issue here than in the case of, say, capital investment planning. Conservatism is also warranted in the estimation of conventional fuel supplies and the need for environmental protection. A risk-averse strategy should dominate in that the objective is the development of options that may be required

under various sets of plausible circumstances. Projections are required of such scenarios such as depletion of oil and gas within forty years, nuclear power plant moratorium, and failure to attain fusion technology.

The energy demand projections serve in this policy area as a uniform information base within which a diverse set of technologies, ranging from insitu coal processing through topping cycles to heat pumps or solar heaters, may be assessed on a comparative basis.

The energy projections must be at least national in geographical scope and must encompass all energy forms and disaggregated demands. The inclusion of causal factors is less critical in general, however price and the effect of changes in the cost of energy on the overall economy may be important.

CAPITAL INVESTMENT

In planning for capital investment in energy supply systems under normal circumstances, near and intermediate term forecasts are required for specific energy forms with a high level of accuracy. Much of this planning is closely coupled with economic activity and these links must be considered in projection methodologies designed for this policy area.

It appears that capital investment is the limiting factor in the growth of demand in certain regions of the country and so long as the situation is supply constrained, demand projections may be easily developed on the basis of projected supply. In these circumstances the investment policy is driven by forces other than demand.

NEAR TERM ALLOCATION OF OIL

There is considerable experience now with this policy issue and it is clear that the requirement here is for very short term (seasonal) projections based on very detailed historical data. Weather forecasts for several months in advance on the regional level are probably the most important component of the demand projection problem. Since the objective is to allocate among users with minimal impact on the economy and a quick reaction to economic dislocations, projections are less important than data on the detailed demands by consuming group and region and the interrelationships between users. Thus this is more of a data management and economic analysis problem than one of projection methodologies.

REGULATION OF RATES AND ENVIRONMENTAL STANDARDS

In this area of policy, accuracy is important in a relative sense but not in an absolute one. It is important here to determine the relative effects, for example, on the supply of natural gas or on the demand for peak electricity of several policy options. Identification of social, economic, and/or environmental interrelationships are also important since such factors are usually involved in the objective to be achieved by regulatory action.

CONCLUSIONS

On the basis of this brief review of the format and style of energy projections needed for a few selected policy issues there is an evident need for a broad spectrum of projection methodologies that focus on elements of particular importance to each application. Attention should be focussed on these special requirements and the assessment of specific methodologies in light of these requirements and on means of checking the consistency between methodologies and justification of differences on the basis of the degree of conservatism reflected or sensitivity to variation in input parameters and assumptions. Less attention should be given to the fruitless quest for perfect or near perfect forecasts or projections as a prerequisite to policy analysis.

Considering the relatively narrowly focussed problem of the pure projection of energy demands several general conclusions may be drawn. In the near term it appears that the situation will be supply constrained and the problem may be reduced to that of gathering data on capital investment and construction schedules. The major component left for the forecasters is that of anticipating OPEC actions and the response of oil conservation efforts that are now developing.

Over the intermediate term any projection that is used as the basis of investment and that assumes a large conservation response is likely to ensure that the situation remains supply constrained and thus will be self-fulfilling. It is less clear that a higher projection, if used as the basis for investment in energy supply technology, will be self-fulfilling by the mechanism of encouraging demand. The major parameters which will affect intermediate projections are the actual abundance of oil and gas supplies, environmental problems, and the success of the nuclear power program.

Long term projections are fraught with most of the difficulties and uncertainties that apply to the intermediate term plus the problem of life style changes in response to societal change or simply to rising energy prices.

Several personal opinions have been expressed in this paper and prejudices have been revealed. It is hoped that these will serve the purpose of stimulating discussion on the important and rapidly growing phenomena of forecasting energy supply and demand.

Table I. Summary of Issues

1. Projections are required to provide a basis for evaluation of policy actions and are inherently imperfect.
2. Need for more sophistication to incorporate policy variables and embed energy system in the economy, society, and environment.
3. Accuracy, scope, format, time horizon and level of aggregation of projection depends on policy issue to be addressed and trade-offs exist between these attributes.
4. Different policy issues may require differing levels of conservatism in projections.
5. How can projection methodologies be validated? Determination of the relative influence of policy variables may be a more important consideration than the absolute accuracy of the projection.
6. Past success or failure of projection methodology may have little bearing on future applicability.
7. Need to identify policy relevance of various methodologies and establish rationale for attributes of a given projection and methodology.
8. Better definition is required of "energy demand." Distinguish between energy form demanded at point of end use and resource requirements to satisfy that demand.

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SUMMARY OF DISCUSSION

The possibility of combining economic and technical analyses was raised. The discussion centered on whether economic analyses could be combined with technologically oriented analyses to focus on specific economic impacts. Past experience shows that coupling energy system models with economic models resulted in a dominance of the economic impacts; in those models examined, rather serious shifts in the energy systems were observed but the economy could accommodate them without changing radically.

The level of detail with which one ought to be modeling was discussed. It has been observed that the more aggregated demand and forecasting models have been more accurate than the disaggregated models. However, it was argued that the inaccuracy may not be due to disaggregation but rather to built-in assumptions of optimism in the less accurate forecasts. Furthermore, the level of disaggregation is constrained by a lack of detailed data for sectoral purchases of fuel by quantity and price.

The problem of the self-fulfilling forecast was discussed. With respect to R&D, if a projection excludes a technology, it may be self-fulfilling because if the projection is used no R&D may take place. A high projection may not be self-fulfilling because implementation of new technology is dependent on many unforeseeable economic, technological, and political factors. From the utilities' viewpoint, there is little meaningful distinction between projections used for R&D investment and projections used for capital investment. Furthermore, the projections made by utilities tend to be self-fulfilling because of the regulatory constraints to which they are subjected. Utilities are required to satisfy all demands for gas or electricity in their service area. Therefore, once a utility estimates what the load will be, it must satisfy that load with the required R&D and capital investment. However, if energy consumption patterns were to slacken markedly due to changes in preferences or lifestyle, then the utilities might be faced with excess capacity and their projections would no longer be self-fulfilling. The use of a conservative projection for corporate investment policy is likely to be self-fulfilling only because the situation is highly supply-constrained.

Hoffman's paper contains the assertion that past success or failure of a projection may have little bearing on its future applicability. This stimulated a discussion on empirical validation of models. For econometric models, testing the stability of the parameters within the sample period could be done for validation. However, for situations which contain a great deal of uncertainty (e.g., the emergence of a new technology), empirical validation is not possible. One solution in this case is the use of subjective probability estimates made by experts, which involves the use of postulates that characterize the way people behave when making assertions about uncertain events.

However, tests of subjective probability forecasting have shown that they are not very reliable due to some intrinsic bias in the assessment procedure.

The question was raised as to whether the future costs of electricity can be predicted from past trends. It was pointed out that the costs could not be projected from past costs trends because of the uncertainties involved in bringing nuclear power plants into service.

DISCUSSION

BENENSON: There are several points you made which I thought would be good for us to focus on during these two days. If anybody has comments about them now, I'd welcome them. You pointed out the rather comfortable outcome of projection by technical analysis, by econometric analysis, and by more general economic analysis. Your point was that in the economic analysis you could get at the overall impact and in a more technologically oriented analysis, you could see the precise impact of a particular technology. Now, what I'm wondering is whether we could combine economic analysis with a more technically oriented approach and zero in to see what are the economic impacts at a more specific level, once we know that there is an overall economic impact that will obtain. Also, there are certain technological changes taking place that are demanding different resources for their development and are having their specific impact. I offer that now as an observation. If anybody has comments about that at this point speak up. I think that would be one of the types of things that we would like to look for throughout the conference.

HOFFMAN: There is a point that seems to be a fairly general consensus, at least among economists such as Allen Manne, Larry Klein, and Tjalling Koopmans at a recent IIASA Conference. They were looking at this question of coupling energy system models to macro economic models, I think Allen Manne best expressed this feeling, that this is a rabbit/elephant stew, with the elephant being the economy and the rabbit being the energy system. It really doesn't make very much difference whether there are one, two, or three rabbits in that stew; it will still taste like elephant. And that seems to be the feeling, that if you look at combinations you see rather serious shifts in the energy system but the economy can accommodate these shifts. These are the conclusions that are coming out of the DRI work or are implied by the DRI work. In that sense, I guess the linkages between the energy system and macro economic models can be rather loose now. I think different criteria again apply to the problems of short run disruptions versus long run dislocations. But I think it would be a very interesting topic to pursue here.

UTSUMI: You discussed how technological analysis has large uncertainties. Then, this technological analysis may give a very imprecise structure to the model.

HOFFMAN: You mean the technological characteristics may be poorly estimated. No. When I talked about our methodology, I think you've seen that our emphasis has been on technology assessment. We've constructed our models with extreme technological detail, so that the technology is there in a framework within which economic interpretations may be drawn or that can be linked to econometric or economic models, but our emphasis has been on relatively extreme technological detail.

UTSUMI: More even than on the detailed engineering?

HOFFMAN: Right. But within an economic context using mathematical programming.

KAUFMAN: I just wanted to raise an issue suggested by this conversation with respect to the level of detail with which one ought to be modeling individual actors in the marketplace, and attempting to model econometrically the behavior of the economic process. There are some disturbing examples. I'm looking at nationwide models that one has to consider very seriously. For example, if you take the approach that in building a national model, you want a very careful examination of disaggregated components, you want microunits very carefully built to mimic what's going on in the financial sector and other such disaggregated sectors before aggregating; then it may turn out that the model that seems to represent the nature of the economic system a bit more accurately is really less viable as a forecasting and predictive tool. The SSRC model is a good example of this, in which each of the individual components was looked at very carefully in great detail, and an attempt was made to put it together; but the damn thing doesn't behave as well as some of Larry Klein's relatively simple macro models. I think we constantly face a certain tension in deciding what our modeling strategy should be, because it is not clear whether we have in the energy area, any really good examples of that type: That is, SSRC versus some simpler model tested for predictive accuracy. I think it's a general modeling question that

as time goes on is well worth working on. We should pay great attention to it.

HOFFMAN: It has been demonstrated that the more aggregated demand and forecasting model has been more accurate than the disaggregated models. They're both simple techniques, but the straight line on semi-log paper for total energy demand has been extremely accurate. Resources For the Future looked in great detail at all of the uses to which energy will be put and projected by trends the use of appliances and the travel of automobiles—they underestimated the 1970 energy demands by 10 or 15 percent.

McCALL: But Ken, don't you feel that they were in effect simply optimistic in almost every situation they looked at? I don't think disaggregation ought to be blamed for their feeling that things were going to get a lot better in saturation of appliances, and so on. I have a problem concluding that. I didn't feel that it was their use of high level of disaggregation which was at fault.

KAUFMAN: That's a good point. There has been much discussion of these issues.

BENENSON: That touches on another point I wanted to raise. You mentioned earlier optimisms and conservatisms in the estimates, and purposes of adopting different projections. You were speaking of the connection between an optimistic forecast or a high forecast and its use for R and D policy. What I'm wondering is whether that might be self-fulfilling, as well as the forecast that is used for allocation of capital, especially in a case where the vendor is doing the R and D.

McCALL: The first question I really want to get at is, why the implication that somehow one is obliged to use only one projection? I really don't agree. I think it is necessary to have a variety of projections against which to consider the policy. You may then go through the kind of thing that I suspect Ken really went through very quickly in developing of the logic as far as R and D is concerned. R and D is front end money and is not big money even for atomic energy. R and D is not really big money compared to what then gets spent when capital equipment is put in place...say for electric power. For fossil fuels, it's even more out of proportion. Take even the kinds of sum that are likely to be spent on coal liquefaction and gasification. Let's take my own company, which has a program that will probably end up spending 200 million dollars of company money on coal liquefaction and gasification. One coal gasification plant will probably run 400-500 million dollars in capital cost and dozens of those will eventually be needed.

So if you are looking at R and D policy or strategy, you look at the high projection and there isn't any path to that projection, or there is no way to get there unless you have that technology, so that R and D falls out of the projection. If you don't do the R and D, then that particular projection is effectively foreclosed. There is always this feedback linkage between policy and the projection. And some times the policymaker would like to discourage perfect projections so that he can make policy. The projection maker would just love to know what the policy is going to be because then he could really do a job on projection.

The next thing you have to do though, once you say that this high projection is at least likely, and perhaps desirable, is to recognize the implicit need for some particular R and D. Suppose then you did the R and D and you got the technology and things don't work out--something happens. Some other energy supply becomes more economical. Then you have to face the fact that you would have pre-invested in the R and D, because any of these things that you extend long enough through the future always lead you, I think, to eventually wanting that technology at some point. It's only the question of whether it comes say within 10 years or over 15 or 20 years, so you would have pre-invested and you might have regrets about that.

The third thing is not an overwhelming point, but in the 30's, there was a real belief that we were going to run out of oil. In Europe there wasn't enough oil. Things were already getting worse. Germany invested very heavily in coal conversion technology. They needed it anyhow as it turned out during the war. But the U.S. also summoned some optimism about coal conversion technology which turned out to be money that generated science and that contributed in some way to R and D but never made any money. That's a very long-winded way of saying: I agree, that high level projections are the better basis for relatively low-cost, long lead-time activity to set policies. Because if you don't link those two together, you go through this wishful operation about some of these other things: everything is going to level off, man isn't going to grow, and we aren't going to need the technology. Then if you don't have the technology you have foreclosed that option.

BREEN: I guess, first of all, not everyone may realize that I work for Pacific Gas and Electric and we have slightly different problems in our need for policy and planning types of projections. With regard to the question of projections made for research and development: first, we have projections made for our own purposes. I don't think that we can distinguish be-

tween projections used for research and development and those made for capital expenditure and capital planning. We face a peculiar situation in that we also are, in a sense, forced to make projections, not only for ourselves and our own policymaking purposes, but because we have to satisfy the regulators too. It is here where we have peculiar legal restraints. In a sense our projections for planning purposes for capital expenditures really become self-fulfilling. There's not much distinction between planning for capital expenditures and for research and development. You become self-fulfilling because of the legal requirements that we satisfy all demands for electric and gas energy in our service area. I hope you at least get the impression that it may be a self-fulfilling projection.

Here in California, because of various circumstances, not all decisions are simple managerial decisions of planning and policymaking. The implications are national in scope in our planning process. You make the projection to provide electric energy. But we are also involved in research and development to improve efficiency in generating electricity. We are able to generate it at a fairly high efficiency and reduced cost, and, of course, this give incentives for population shifts that are national in scope, especially for industrial users who might be high energy demanders.

Another issue that was brought up here is: because we are regulated, the conventional thinking is that projections for policymaking, whether they are towards planning, research and development, or capital expenditures, or for any other purpose, should be all in one projection. For instance in our company, we don't have the option of having conservative and a liberal policy on projections. And so, I think this is something that might have to be taken into consideration as far as any energy modeling effort is concerned. That in the aggregate, as an example, the constraints may somehow offset each other, but there is a particular need for disaggregation to take into consideration peculiar constraints that are issued to a particular sector (in this case, the energy utilities.) They face a set of constraints that are imposed upon them by the regulators.

BENENSON: I think that's really interesting; the possibility that we can use different projections for different types of policy questions. One thing that comes to mind is this. If the forecast is in fact self-fulfilling, and if you were to seek either the forecasting method or a set of assumptions which would give us a lower forecast, could we bring about that situation as opposed to the situation consistent with a higher forecast?

BREEN: Well, let me backtrack one step. I said that we get the impression that these projections were self-fulfilling in the historical data. However, in very recent times, concerning planned capital expenditures with thermal generating plants to come on line 10 years from now, these plans are being given second thoughts, not just by Pacific Gas and Electric, but by everybody; due either to some kind of spiritual conservation ethic brought into the arena, or perhaps more likely, due to the effects of price increases on the demand for electricity. And so, utilities in general, because they are regulated and they are in a sense told that they must satisfy all demands, do their planning on the basis of having a very conservative margin of reserve capacity to satisfy all demands. This is not just a peaking problem, but also to ensure response to growth in demand. But the data now tell us a slightly different story. Whatever the reason is (for example long-term conservation efforts or increases in the price of energy) energy demand by the consumer has dropped and so this is altering many final decisions after the fact. It's not clear yet what will happen. I think, first of all, in the utility industry, the planners themselves have lived through a rather long stable growth period of energy demands. Their thinking is along these lines, and so their thinking will be to satisfy the legal requirements that they satisfy all demands. There needs to be some backtracking in this thinking and the solutions haven't presented themselves. I'm not sure that anyone has given enough serious thought to this. The fact of the matter is that because we are reacting to regulatory bodies solutions may have to be imposed from outside the industry.

HOFFMAN: I agree with you. It seems to be our consensus that projections about research and development are not self-fulfilling. And I also feel, with regard to investment policy, that a conservative capital facility investment policy is likely to be self-fulfilling only because it imposes a supply constraint on the situation. I'm not so sure that if you had a very aggressive investment policy it would necessarily be self-fulfilling. I think perhaps regionally it might but, if one had a national plan, a national commitment to expand capacity, I don't feel that would necessarily be self-fulfilling. I've talked to people in the United Kingdom who went through a phase about five years ago where they had excess installed capacity and wished that their investment plans were self-fulfilling.

With regard to the distinction between a projection for R and D policy and for investment policy, I don't think the utilities have a reputation of engaging in aggressive research and development programs. So, I think possibly, that distinction is not very important.

BREEN: I should have brought that point out a little bit. Essentially, I think utilities are purchasers of

research and development efforts from the likes of Westinghouse and G.E.

HOFFMAN: If you look at EPRI, it will be interesting to see what kind of national projections they use as a base for their research and development strategy. It seems already predetermined that the level of their research and development effort is keyed to current sales of electricity in some fixed percentage, so perhaps that obviates the need for any kind of projection at all. Their level of R and D investment is essentially fixed irrespective of what one sees in the future. Of course this percentage may be modified if it seems more appropriate to plan for the zero-energy growth scenario.

BREEN: Perhaps we're talking about two different types of policy analysis. In fact we are. One is at a micro level. For instance I spoke to the individual corporation and its policy and strategy plan. One is at the macro level, where the Federal Government is speaking of its policy for research and development. It may even be appropriate for each utility to perhaps almost disregard research and development as an internal operation; or it may not. I'm not sure at this point.

HOFFMAN: And you do need sharpening of the policy needs on the basis of the federal level, state level, and the utility.

BREEN: I'm sort of at a loss to stick to policy analysis, if we're going to address mostly a governmental policy-making analysis situation, since I am only involved, in a sense, in the micro level.

GRIFFIN: I think we all agree that our forecasts are inherently imperfect. Several things have bothered me, however. On page 2, you say that given the fact that the future is essentially unknowable, "It's probable that increased sophistication in methodologies with the single objective of improved accuracy is inappropriate and counter-productive." Then, on page 6, you say that "past success or failure of projection methodologies may have little bearing on future applicability." Well, this kind of bothers me because it doesn't leave us with a very good criterion for deciding what's a good methodology. The point is that now with so much money being spent in energy, we are going to see a lot of models, and these models may generate more bad policy. But yet they attain sort of an awe or respectability with policy makers who really are nontechnicians, who listen to them and base their policy on them. And it seems to me that more than anything, we ought to be trying to define the methodologies that are appropriate for looking at specific types of problems. If people develop a methodology along those lines and they report that it can deal with a certain kind of policy question, I think we should require that they demonstrate that it has at least in the past provided a basis for prediction, and that they provide some rationale for why it's likely to work in the future. For example, in econometric applications, there are tests for stability of parameters. We hardly ever run these tests. You know what happens: We get a nice fit over the sample period and the sample period runs out in 1973, so that we really can't see how the model predicts beyond that. We never examine for stability of coefficients within the sample period. I think it's important that we take a much more rigid approach and this may help us weed out inappropriate methodologies.

HOFFMAN: I think there is a great danger with great expansion of modeling systems. It adds quite a bit of noise to the system.

KAUFMAN: This is a very interesting point, and I think what you're saying makes a lot of sense when you're dealing with models that are structured in such a fashion that they have a capacity to be empirically validated. And that's certainly true with much of the econometric modeling that's going on in the energy sector. On the other hand, there is a whole class of forecasting problems in which we just don't have either the opportunity or the luxury of being able to test. For example, exotic new technology or even not so exotic new technologies, such as the date when the breeder will come on-line, the date when we can consider fusion as some kind of viable energy option, if at all. These in essence fall within the realm of subjective probability. The only way that you can get a handle on subjective probability is to say that we have a set of postulates or axioms that characterize the way we wish to behave in making assertions about how uncertain quantities behave. We want to behave in accordance with those axioms and postulates, which leads to the notion of subjective probability. But they're one-shot things. They're not replicable. I'd be interested in hearing some reactions as to how, in light of these important comments about empirical validity, we behave in the face of those facts. What do we do? Do we issue forecasts, or do we forego doing that kind of thing?

GRIFFIN: I don't see how you can guess for some new technology. I really don't see how you can when you obviously don't have a sample period to look at. But, you know, it seems to me there is another whole set of questions that sort of involve perhaps economic and social responses, that we may have some basis for predicting on the basis of past observation.

KAUFMAN: There is another fact worth pointing out here. We do have some marginal information that I think bears on this discussion, empirical information that doesn't have to do with the empirical validity of the subjective probability of the forecasting mechanism in this kind of setting, but rather with the empirical validity of forecasters who use subjective probability. That experience is very disturbing, because we hear a lot of discussion about the Delphi method eliciting expert subjective judgments about future technologies, etc., etc. And, that's fine, except for some reasonably carefully controlled experiments that a number of us have been performing for quite a long time with people in the oil industry. For example, we presume they know something about oil exploration, so we ask some questions about oil exploration. We have marketing people, so we ask them marketing questions. It all turns out the same: when people are assessing fractiles for continuous uncertain quantities they find it extremely hard to say what they really mean to empirically validate. I mean that in the sense that if they say, for this uncertain quantity, here is my subjective 50/50 probability interval, and you ask a series of questions of an individual like that, you would expect that if he says 50/50, on the average, that interval would cover 50% of the true quantities. The average on the first round is 36%. As much as I like subjective probability, I'm going to be very, very mistrustful of subjective probability assertions. I don't see any way out of the box.

GRIFFIN: Well, I think that clearly in the area of R and D, that's your only way out.

McCALL: When you said the word validation, does that have some very special meaning?

KAUFMAN: It does have a special meaning. It's the following concept. Let's take a list of one hundred uncertain quantities, such as, for example, the number of tankers over 200,000 tons presently on order around the world. That's an uncertain quantity for you. But its something I can go and look up. So, I ask you to give me an interval such that you think there's a 50/50 chance that in your personal judgment, given what you know, there is a 50/50 chance that that interval will cover the actual value. That's a 50/50 betting average. I ask you a hundred questions of this kind, then I ask you another hundred. You would "empirically validate" if, as the number of the questions that I ask increases, the relative frequency with which your 50/50 interval covered the true value got closer and closer to 50%. That is a crude way of saying it. One can of course make it more general. But that's the kind of "empirical validity" that I'm talking about for subjective probability forecasting. I think it is very important. If you see that with a large group of people, 50-50 credible intervals cover the answer only 36% of the time, then there is a certain kind of intrinsic bias that has something to do with the assessment procedure. If you are in a situation (as we are with many of these energy problems) where an explicit characterization of the riskiness of a policy or an alternative ought to be considered, then that kind of bias becomes very important.

McCALL: What Jim is talking about as far as validation is concerned is some sort of goodness of fit.

GRIFFIN: Well, you can examine it over the sample period if you have prior observations which sort of conform to what you expect might happen in the future. I think, too, you can probably subject things to sort of an imprecise common sense examination. I think that this is absolutely essential.

McCALL: I have a hard time getting to the point I'm trying to raise. Maybe you can invalidate something by a test over the sample period. I don't think you can, in my sense of the word, "validate" it. You have to feel that you have linkages between causation and effect that are driving whatever it is that you are trying to describe and that can reasonably be expected to drive it in the future. And what the model is doing in a very oversimplified way is giving you estimates of the parameters, but it doesn't validate it...it doesn't prove it. The goodness of the fit doesn't prove a thing.

GRIFFIN: Yes, but if it fails over the sample period?

McCALL: Then you would reject it.

GRIFFIN: I'm ready to disregard that model.

McCALL: Well, he's talking about methodology, he's not talking about a particular model.

GRIFFIN: All right, but what I'm saying is that if a methodology fails to describe a thing that it is purported to describe...

HOFFMAN: If there were a methodology that didn't include price effects and failed over the past 10 years, and you can attribute that failure to that cause, then I would not throw that model away.

GRIFFIN: Well, I would call it a new model if you built another one in the process.

HOFFMAN: No, because it may for the next ten years project a relatively stable price level and I would go ahead and use that model with greater confidence than I had in the past. If it failed, then I know why it failed, and now in my new projection the mechanism by which it failed would not be operative.

GRIFFIN: You're assuming that.

HOFFMAN: All of these projection techniques just push the projection problem back one step further.

McCALL: Well, it would take a little effort, but you should go and build price into it and then go fit the sample.

HUDSON: It seems to me that on this validation of the historical period, the usual econometric techniques are suspect. For example, for the reason that you say they can't fix causation. The more I work in this area, the more I downplay the usual test of significance. I'm coming to the view that the most powerful means of testing is to run a dynamic simulation on this historical period, then just to eyeball it and see if it fits.

HOFFMAN: You mentioned, I think, that you had done this with your model. That's the kind of validation you prefer to assist in the fit?

HUDSON: Conceptually, I wouldn't because of this problem of causation and especially because the...

HOFFMAN: The multicolinearity problem?

HUDSON: Yes, but now the underlying structure... especially if prices have changed and if you are not picking up this causal structure, then you are not getting anything.

HOFFMAN: And you may have verified that you have picked up that causal structure with a ten percent variation in price, or it may have failed with a ten percent variation in price, but it may work with a fifty percent variation. You might throw something out that would be good for the future in regard to price changes.

GRIFFIN: I'll turn it back to you. How do you select a good methodology? If price is no basis for the future, and causation no basis because you have already said that if prices really don't matter...

HOFFMAN: I try to downplay the need for accurate projection techniques as the basis for policy.

GRIFFIN: Now, on what basis do you base policy, then?

HOFFMAN: For some policy, you consider a conservative projection. For an R and D policy, you consider a high projection.

GRIFFIN: But I have trouble putting numbers in to help me select high or conservative or so forth.

HOFFMAN: Well, I do too. What we thought was a high projection turned out to be the lowest projection around at the time.

GRIFFIN: Based on what?

HOFFMAN: Well, we made very arbitrary assumptions, like in the year 2000, that everybody will have a central air conditioner; that everybody ought to travel to Europe and Asia once a year, and like that.

BREEN: How do you know you even have a most likely projection, a high projection and a low projection, unless you have some way to go back and review these?

HOFFMAN: Well, that projection was subjected to, I guess, what you might call a modified Delphi technique.

GRIFFIN: You shouldn't have said that.

HOFFMAN: And half the people thought it was too high and half the people thought it was too low, and we thought it was just about right.

KAUFMAN: I perhaps should put in a caveat. Certainly people can be trained to know what they're saying when they talk of subjective probability.

HOFFMAN: It sounds like all we have to do is multiply everything by 50 over 36 and you're right on.

KAUFMAN: No, no, no. It comes out better the second time you do it. People get closer.

BENENSON: I don't have a response to make to the difficulty you may have, but I'm glad you brought it up because that is the sort of thing that we want to bring out. And I also think that this problem of how you assess a method still has to be pursued. We still need to be able to distinguish between a family of methods that will give us a particular kind of forecast to be used for a certain kind of policy.

HOFFMAN: Right, and in doing that and looking at this family of methods I think that in many meetings people stress the technical nature of these methodologies, that we should use this and not that, and process analysis is better than econometrics, and econometrics than some other technique. I think we should focus on the complementarity of these techniques and how one might be used to reinforce the other one.

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A PROBABILISTIC MODEL OF THE OIL AND GAS DISCOVERY PROCESS

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SUMMARY

Kaufman presented a probabilistic model for the discovery of petroleum deposits. Two assumptions are made regarding the distribution of reservoir sizes, and its relationship to the discovery process for reservoirs within a region of uniform geological characteristics, called a "play":

1) The size distribution within a subpopulation is log-normal.
2) The probability of discovering a reservoir is proportional to its size.

Kaufman then presented a statistical analysis of data from plays in Alberta, Canada to support the assumption that the underlying distribution is log-normal. He went on to estimate the expected sampling distribution of reservoir size in chronological order of discovery. Since the largest reservoirs are most likely to be discovered first, the sampling distribution deviates from a log-normal distribution, which leads to an overestimate of the amount of petroleum remaining in place. A Monte-Carlo computer simulation of the discovery process was described. The results showed the effect of sample size on the shape of the distribution. Kaufman intends to refine the model to get approximations to the sampling distribution that would lead to a better estimate of oil in place. Further work will be done to incorporate this physical model into an economic model, to investigate the optimum investment strategy for the development of a play over time.

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A coherent national energy policy cannot be formulated without reliable estimates of the quantities of oil and of natural gas remaining to be discovered in U.S. territories supplemented by a forecast of what fraction of each can be recovered using currently available technology. Unfortunately, there is wide disagreement about what methods should be used to generate these estimates as well as about their magnitude: the highest publicly cited estimates of recoverable oil remaining to be discovered is about eight times the lowest!

Since a rational national energy policy based on the lowest of these estimates may differ radically in form from one based on the highest, the development of methods for estimation of oil and gas reserves that have scientific credibility and that simultaneously generate estimates in a form immediately useful for policy analysis is of critical importance. Unfortunately, none of the methods currently employed to estimate amounts of undiscovered oil and gas recoverable using current technology possesses both of these desirable attributes. The primary purpose of the research program proposed here is to develop methods that possess both. In order to be scientifically credible, a method must be based on explicitly stated postulates whose validity can be empirically validated using observed data. In order to be useful for policy analysis, it must provide not only single-number estimates, but an explicit measure of the degree of uncertainty each such estimate possesses.

In addition, it should be designed so as to allow construction of an economic supply function; i.e., a description of how additions to reserves from new discoveries behaves as a function of well-head price, exploratory effort, and the costs of exploration. Namely, our goal is the construction of a predictive model which provides probabilistic answers to two questions:

1. How many undiscovered pools remain in a given region, and what is their size distribution?
2. What additions to economically exploitable reserves will accrue from an increment of exploratory effort?

The model can be interfaced with expert subjective judgment to provide an answer to the first question for as yet unexplored areas, as well as for areas where data on drilling successes and failures and sizes of discoveries has been generated by exploration activity.

It is a process oriented probabilistic model. By "process-oriented" we mean a model that explicitly incorporates certain geological facts and in addition is

*An expanded version of this paper will appear in an AAPG Memoir from an AAPG Symposium, Stanford University, August, 1974. (Work supported by NSF Grant GI-34936).

based on assumptions that describe the manner in which exploration technology and observed statistical regularities of the size of pools interact to generate discoveries.

The model of the discovery process we propose has four major components:

1. a sub-model of pool sizes discovered in a homogenous geological population of pools in order of discovery,
2. a sub-model of wildcat drilling successes and failures,
3. a sub-model of the economics of a single exploratory venture,

and

4. a sub-model of the "capital market" for exploratory ventures.

When assembled, these sub-models constitute a probabilistic model of the returns in barrels of oil and/or MCF of gas generated as a function of price and physical nature of the reservoirs available for exploitation. Here we shall discuss properties of only the first of these four components.

1. THE DISCOVERY PROCESS

"Discovery process" is a descriptive label for the sequence of information gathering activities (surface reconnaissance, magnetic, gravimetric, and seismic surveys, for example) and acts (drilling of exploratory wells) that culminate in the discovery of petroleum deposits. In building models of it, we will regard it as being effectively described by a small number of quantitative attributes (such as the number of exploratory wells drilled into a geological formation in a given area and the oil (gas) in place in a newly discovered pool, and postulated relations among them. While doing descriptive injustice to the way in which geologists extrapolate geological facts to guide exploratory activity, a model composed solely of such attributes can embody many of the essential features of the discovery process.

A petroleum basin or area the size of Alberta will in general contain reservoirs or pools with distinctly different geological characteristics. We shall regard the totality of pools in Alberta as being classified into a collection of sub-populations of pools of similar geological type. By definition, a *play* begins with the exploratory well that discovers the first reservoir to be discovered in a sub-population. Thus there are in principle as many potential plays as sub-populations or geological types. The choice of typology depends on the use to which it will be put; our choice will be coincident with a generally agreed upon description of major plays in Alberta; e.g., Cardium, D-2, D-3, Viking, Beverhill Lake, etc.

A key component of our model is a set of (probabilistic) assumptions which govern the behavior of additions to oil (gas) in place as a function of the number of wells drilled in a play. When plays are set in relation to one another on a time scale, *total* additions to oil (gas) in place in a given time interval may be regarded as generated by a temporal *super-position* of individual plays. One might also superpose plays on a scale composed of the cumulative number of exploratory wells drilled in the province. A model that effectively describes the behavior of the number of exploratory wells drilled into each play in any given time interval automatically generates a description on this scale.

To the degree that we can separate physical and engineering aspects of the discovery process from economic considerations, we shall do so. A partitioning of assumptions into two classes, one physical and the other economic in character, leads to substantial simplifications both in the structure of the model and in procedures for making inferences about its parameters. In particular, classification of pools into geologically homogeneous sub-populations leads to a corresponding statistical homogeneity of the economic attributes of reservoirs within each sub-population. So doing enables us to trace the influence of price, exploration costs, and development costs on additions to reserves from new discoveries in a much more meaningful way than if all sub-populations of pools are aggregated into a single population.

Assumptions about the physical nature of the discovery process are presented first. They are stated in a way which tacitly implies that economic variables may influence the temporal rate of drilling exploratory wells in a play, but they do not affect either the probability that a particular well will discover a pool or the size of a discovery *within a given play*. This assertion is patently false if applied to a population consisting of a mixture of sub-populations with widely varying geological characteristics. For example, a large price rise may accelerate exploratory drilling in high risk (low probability of success) sub-populations with large average pool sizes at a substantially different rate than in sub-populations with small pool sizes but high success probabilities. The overall probability of success for a generic well among the wells drilled in a mixture of these sub-population types as well as the size of discovery will depend on the relative proportions of wells drilled in each sub-population and these proportions are influenced by prices and costs. By contrast, it is reasonable to assume that within a given sub-population the precision of information gathering devices and quality of geological knowledge of that sub-population are the principal (perhaps sole) determinants of the probability of success of a generic well. A price rise may

accelerate the temporal rate of drilling within that sub-population, but it will not affect the quality of geological knowledge at any given point on a scale of cumulative wells drilled into it. Exceptions can of course be found, but as a broad descriptive principle it is plausible. As stated earlier, its adoption yields important analytical bonuses: it simplifies the modeling process and allows us to be parsimonious in choice of parametric functions for components of the model.

2. PHYSICAL POSTULATES

Our postulates or assumptions about the physics of the unfolding of a play reflect both petroleum folklore and the content of a variety of statistical and analytical studies of the discovery process. The principal ones are:

I. The size distribution (in barrels or MCF) of petroleum deposits in pools within a sub-population is lognormal.

II. Within a sub-population the probability that the "next" discovery will be of a given size (in barrels or MCF) is proportional to the ratio of that size to the sum of sizes of as yet undiscovered pools within the sub-population.

The probabilistic behavior of amounts of oil (gas) in place discovered by each discovery well *in order of discovery* is completely determined by a conjunction of assumptions I and II; i.e., our submodel of pool sizes is composed of I and II. Assumption II implies that "on the average" the larger (in size of oil (gas) in place) pools will be found first and as the discovery process depletes the number of undiscovered pools in a subpopulation, discovery sizes will (again, "on the average") decline.

3. EMPIRICAL SIZE DISTRIBUTIONS

Empirical size distributions of oil pools are usually unimodal and skewed with very long right tails; i.e., a small proportion of observed sizes are very large and a large proportion are very small. The problem of determining which, among all functional forms for unimodal distributions concentrated on zero to infinity and possessing long right tails, best fits observed pool size data is complicated for several reasons: reported pool sizes (in barrels in place or in barrels of recoverable oil) are usually only engineering estimates and may be substantially biased. Oftentimes a small, uneconomic pool is recorded as a "dry hole" rather than as a pool, introducing an effect akin to truncation of sample observations. And when the discovery process is one in which observations of pool sizes are made by sampling without replacement and proportional to random size, the joint distribution of discovery sizes are not independent and the marginal distribution of an individual discovery is not the same as the size distribution of pools in nature.

A test of the specific hypothesis that the probability law of observed sizes has a functional form dictated by assumptions I and II is quite difficult due to the complexity of the sampling density so implied. As a crude pretest, however, we can use an existing program* to test the hypothesis that *observed* pool sizes are lognormally distributed against the specific hypotheses that they are gamma distributed. It is designed so that both hypotheses may be simultaneously rejected or simultaneously accepted. One would expect that if the sample size is small both hypotheses will be accepted and if the sample size is large and the size distribution in nature is lognormal, then both hypotheses will be rejected. At the 1% level of significance this latter event occurs only once among twenty-one samples—but significantly, the sample size for this case is very large by comparison with all other cases. When plotted on

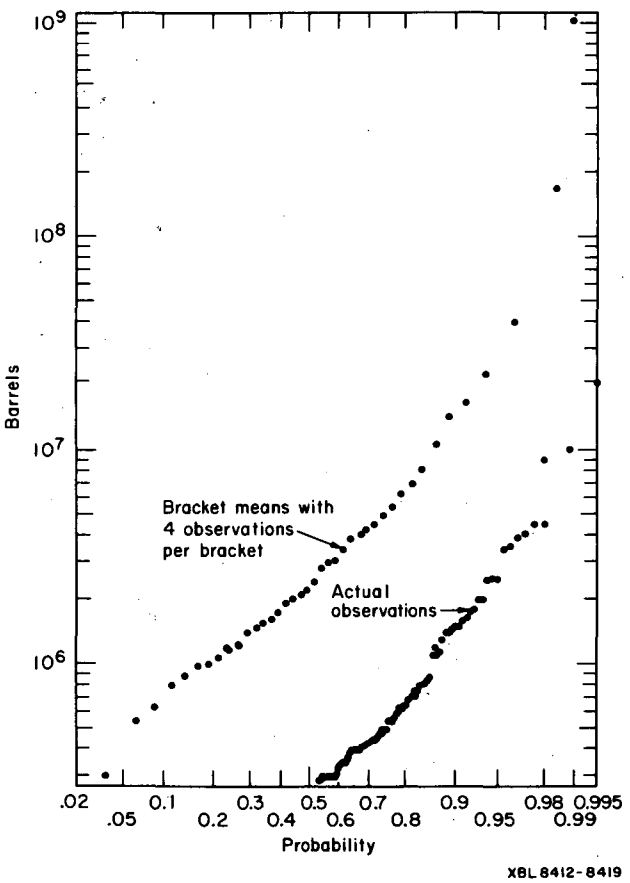

Fig. 1. Keg River 7880 (195 observations).

*Developed by Karen Sharp, Energy Resources Conservation Board.

lognormal probability paper most of the twenty-one samples show substantial deviation from lognormality in the extreme tails. The implication is that with much larger sample sizes both the lognormal and gamma hypotheses may be decisively rejected. A typical graph displaying a "fat" right tail is shown in Figure 1.

4. PROPERTIES OF ASSUMPITONS I AND II VIA MONTE CARLO SIMULATION

In order to give an intuitive "feel" for the implications of assumptions I and II we describe here the output of a monte carlo simulation of the sampling process for discovery sizes dictated by them. Our attention here is focused on three objects:

1. The probability distribution $P\{\tilde{Y} \epsilon d\underline{Y} \mid \underline{\theta}, N\}$ of observed sizes $(\tilde{Y}_1, \ldots, \tilde{Y}_n) = \underline{\tilde{Y}}$
2. The probability distribution of undiscovered sizes given $\underline{\tilde{Y}} = \underline{Y}$,

and

3. The probability distribution of the mean $\tilde{\bar{S}}_{N-n}$ of undiscovered sizes given $\underline{\tilde{Y}} = \underline{Y}$.

We will examine 1. and 2. relative to assumption I in the following way: assume that the size distribution of petroleum deposits in pools is lognormal with parameter (μ, σ^2); i.e., $\tilde{A}_1, \ldots, \tilde{A}_N$ are mutually independent with common density for $-\infty < \mu < +\infty$ and $\sigma^2 > 0$,

$$f_L(A \mid \mu, \sigma^2) = \begin{cases} \dfrac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\log_e A - \mu)^2/\sigma^2} \dfrac{1}{A} & \text{if } A > 0, \\ 0 & \text{otherwise} \end{cases} \quad .(.1)$$

To simulate observations generated according to assumptions I and II, we first generate values $A_1^{(i)}, \ldots, A_N^{(i)}$, according to (.1) and then, given $\{A_1^{(i)}, \ldots, A^{(i)}\} \equiv Q_N^{(i)}$, generate $\underline{Y}^{(i)}$ according to I and II. Here the index i indexes replications of our monte carlo experiment. It is obvious that elements of $\underline{\tilde{Y}}^{(i)}$ are neither independent nor marginally identically distributed as lognormal. However, suppose that we incorrectly assume that they are and examine fractile plots of the $Y_j^{(i)}$s on lognormal probability paper as if they constitute independent sample observations from a lognormal process—as has been done by a number of authors. How does the empirical cumulative function so generated deviate from lognormality? Undiscovered sizes, the complement $U_N^{(i)}$ of $\{Y_1^{(i)}, \ldots, Y_n^{(i)}\}$ in $Q_N^{(i)}$, are treated similarly in our experiment.

Not wishing to hold the reader hostage to uncertainty, here are the salient facts:

(a) On lognormal probability paper the graph of fractiles computed from $Y_1^{(i)}, \ldots, Y_n^{(i)}$ is on the average close to linear within the interquartile range, but exhibits a fatter right tail than that possessed by a lognormal distribution. The graph is tilted with smaller slope than that exhibited by the (straight line) graph of fractiles of the underlying lognormal distribution of the $\tilde{A}_j^{(i)}$s and lies entirely *above* the latter graph.

(b) The graph of fractiles computed from undiscovered sizes is on the average linear within the interquartile range but exhibits a smaller right tail than that possessed by a lognormal distribution. It is also tilted, with smaller slope in the interquartile range than that of the graph of fractiles of the underlying lognormal distribution and lies entirely *below* the latter graph.

In order to reduce the effects of Monte Carlo sampling variability, we replicated our experiment one thousand times, and display for the example described below graphs of the sample means of fractile estimates cited above. In addition we computed sample estimates of the marginal means of the $\tilde{Y}_j$s and of the covariance structure of $\underline{\tilde{Y}}$. Coincident with our intuition:

(c) The mean $E(\tilde{Y}_j \mid \underline{\theta}, N)$ of the size of the jth discovery is far above the mean of the underlying (lognormal) population for small values of j, but declines faster than exponentially with increasing j at first and then declines slower than exponentially.

(d) The distribution of $\tilde{Y}_j$ is very close to lognormal for small j, but as j increases, right tail probabilities become smaller than those of a lognormal distribution with the same mean and variance.

The graphs displayed in Figures 2 through 7 were generalized by averaging 1000 Monte Carlo replications of sampling n pool sizes without replacement and proportional to random size from a finite population of N pools. Values chosen for n and N were

$$\left.\begin{aligned} N &= 1200 \\ &= 600 \\ &= 300 \end{aligned}\right\} \quad \text{and } n = 10, 20, 30, 40, 50, 75, 100, 150, 200$$

$$N = 150 \quad \text{and } n = 10, 20, 30, 40, 50, 75$$

$$= 100 \quad \text{and } n = 10, 20, 30, 40, 50$$

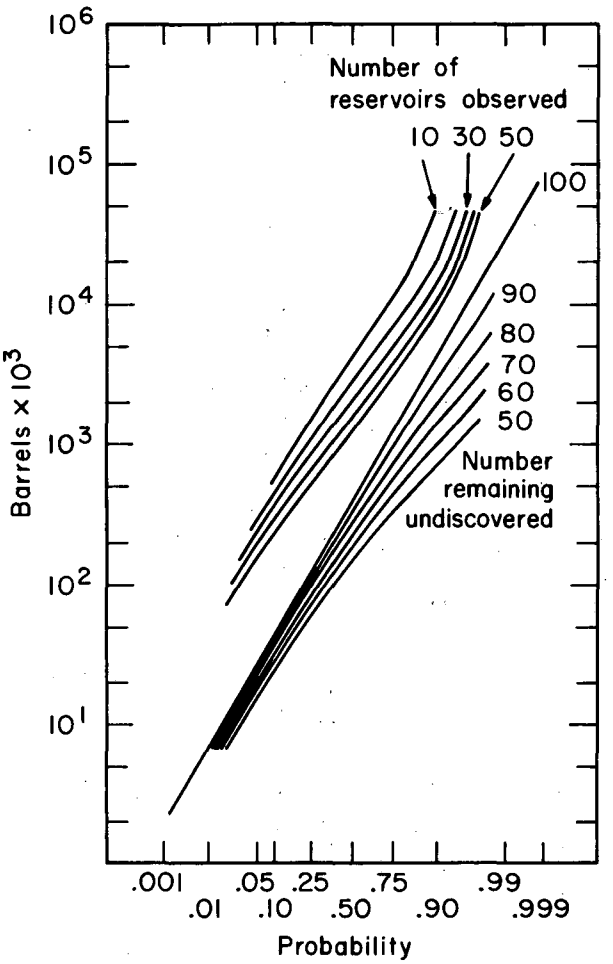

Fig. 2. Simulated cumulative distribution functions for observed pool sizes and for reservoirs remaining undiscovered when N = 100.

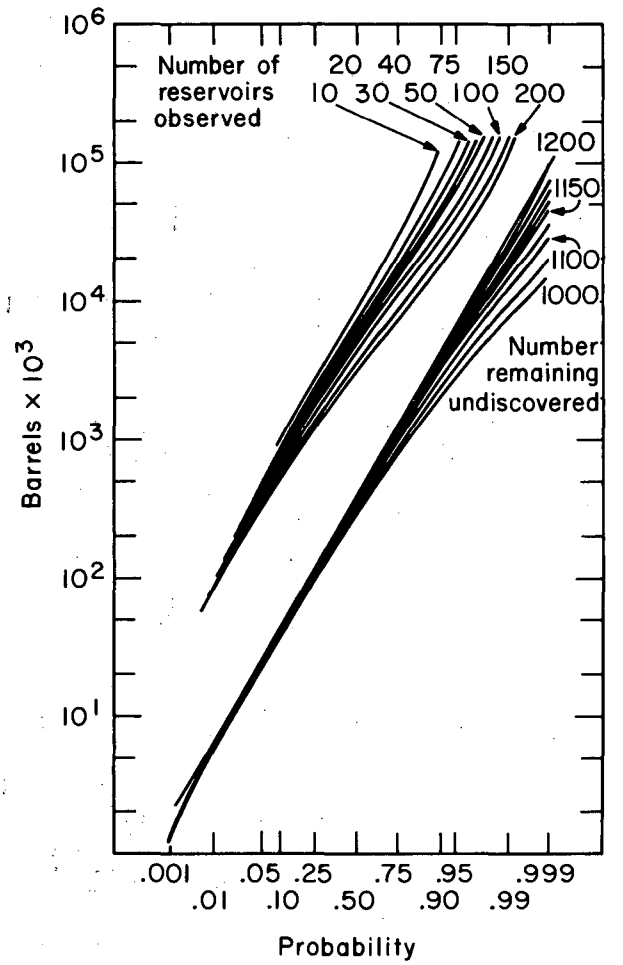

Fig. 3. Simulated cumulative distribution functions for observed pool sizes and for reservoirs remaining when N = 1200.

Elements of the finite population have sizes generated according to a lognormal probability law with parameters $\mu = 6.00$ and $\sigma^2 = 3.00$. In 10^3 barrels of oil in place the corresponding density has median $\exp\{6.00\} = 403.4$ and mean $\exp\{\mu + \frac{1}{2}\sigma^2\} = 1808$.

The figures display simulated versions of (a) the expectation of the empirical cumulative distribution function of observed pool sizes, and (b) the expectation of the empirical cumulative function of sizes of pools remaining to be discovered computed under the assumption that observed sizes are mutually independent and identically distributed—which they are not. The graph is plotted on lognormal probability paper with ordinate expressed in natural logarithms and abscissa in probabilities of less than the corresponding ordinate values. By computing this expectation and plotting it as described, we can see how far "off" we are by making the assumption that observed sizes are in fact independent and identically distributed as lognormal. The right tail curves noticeably away from a straight line and is displaced upward from the straight line (graph) of the underlying population's cumulative distribution function.

The graph of the expectation of the empirical cumulative distribution function for given N and n plotted in a similar fashion lies below the straight line (graph) of the underlying population cumulative distribution function with right tail that gets progressively "thinner" as a larger proportion of the finite population of pools is sampled.

Figure 4 displays the graph of the (simulated) mean of observed pool sizes in order of discovery for several values of N. The first few discoveries have mean sizes orders of magnitude greater than the mean size of $\exp\{\mu+\frac{1}{2}\sigma^2\} = 1{,}808{,}000$ barrels in place of the underlying lognormal population. For example, when N = 100, the mean size of the first discovery is over twelve times the underlying population mean and when N = 1200 is over seventeen times this mean! The mean size of the jth discovery declines at a very rapid rate; e.g., for N = 100, only the first twenty discoveries have mean sizes larger than the underlying population mean.

Figure 5 shows graphs of (simulated) means of observed pool sizes in order of discovery for several values of N as a function of the proportion of undiscovered pools that have been discovered; i.e., $E(\tilde{Y}_j|\underline{\theta},N)$ is plotted as a function of j/N-j. As N varies from 100 to 1200, the graphs remain virtually indistinguishable. If they are in fact indistinguishable the implication is that $E(\tilde{Y}_j|\underline{\theta},N)$ is the same for every pair (j,N), $j < N$, of positive integers such that j/N-j is a constant; i.e., $\lambda = j/N-j$, $j=1,2,\ldots,N-1$ is the "natural" scale for $E(\tilde{Y}_j|\underline{\theta},N)$.

5. DRILLING SUCCESSES AND FAILURES AND DRILLING RATES

Often a play begins with a stroke of geological insight. Given this insight, application of geophysical technology coupled with geological analysis will identify a population of prospects some of which will be pools

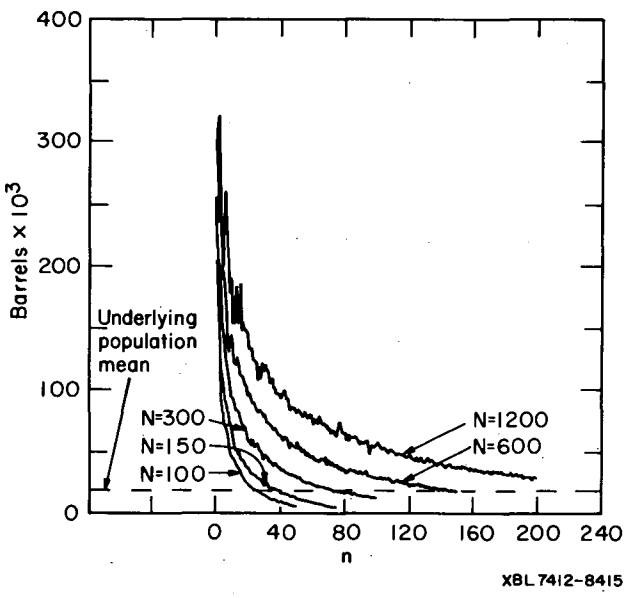

Fig. 4. Simulated means of size n-th pool discovered for finite population sizes N = 100, 150, 300, 600, and 1200.

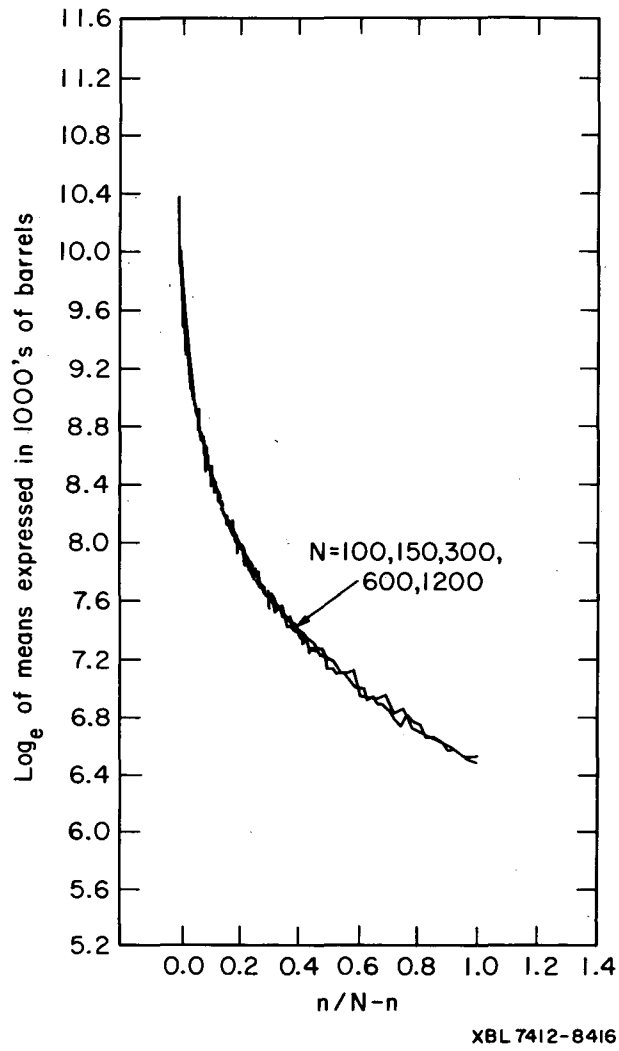

Fig. 5. Simulated means of size of n-th pool discovered for finite population sizes N = 100, 150, 300, 600, and 1200 displayed as a function of n/N-n, the proportion of undiscovered reservoirs discovered.

and others of which will be dry. Letting S denote the sum of sedimentary volumes of all undiscovered pools in the play and letting U denote the sum of sedimentary volumes of all undrilled prospects that are potentially identifiable using currently available exploration technology, we state

III[a]. The probability that an exploratory well will discover a new pool is equal to

$$\frac{\kappa S}{\kappa S + U}$$

where $\kappa > 0$ is a constant.

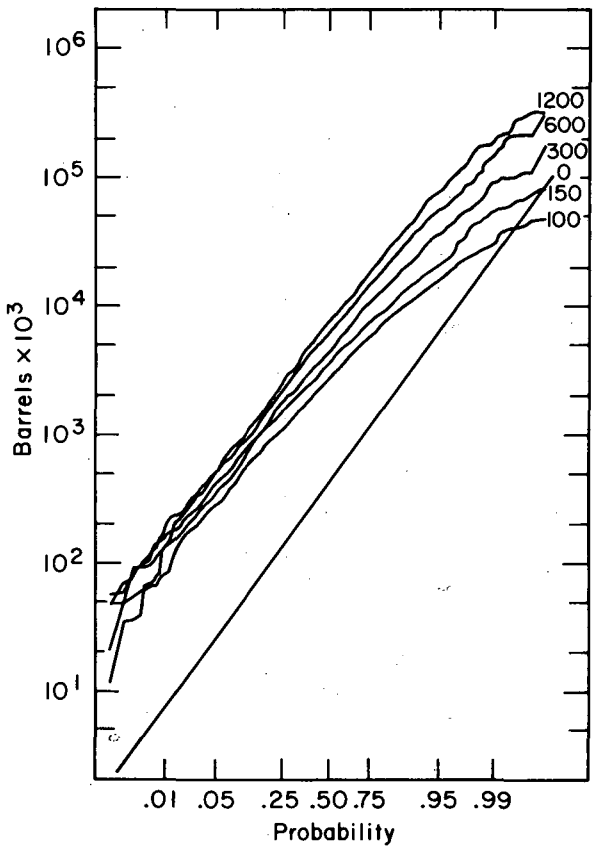

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Fig. 6. Simulated cumulative distribution functions of size of 10th pool discovered when finite population size N = 100, 150, 300, 600, and 1200.

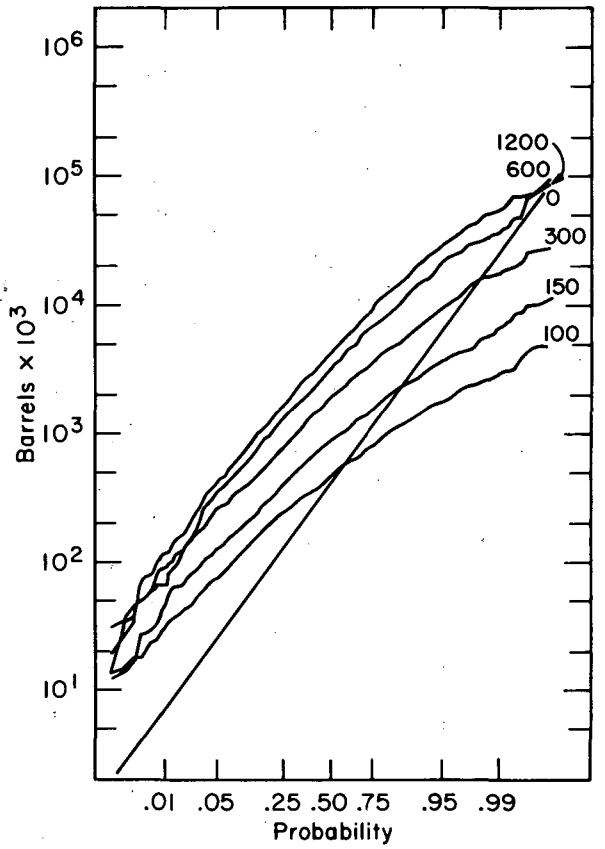

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Fig. 7. Simulated cumulative distribution functions for size of 50th pool discovered when finite population size N = 100, 150, 300, 600, and 1200.

The constant κ is to be interpreted as an index of the difficulty (or ease) of discovery of pools within a given sub-population *once a play has started within it.* Hence it may vary from sub-population to sub-population. (For example, stratigraphic lense traps are more difficult to identify with seismic than pinnacle reefs and so might be assigned a smaller value of κ). Assumption III is an extension of the idea behind assumption II (sampling proportional to size) and says that the probability of a discovery of *any* size shares the same general property. If the value of κ—the index of difficulty (or ease) of discovery—is one, then drilling is "random" in the sense that predrilling exploration technology does not enhance the probability of discovery. Exploratory drilling in this particular case is like throwing darts into a three-dimensional volume, each piece of equal volume having the same probability of being hit no matter where it is located. Even in this special case the probability of discovery will change as the above mentioned ratio changes with each exploratory well drilled.

A variant of III^a is to replace "volume" with "areal extent": call this assumption III^b. It is a more natural assumption than III^a in certain respects. If drilling is completely random with respect to longitude and latitude, then the probability of a generic pool being discovered is exactly equal to the ratio of the areal extent of the pool to the total areal extent of all undrilled prospects in that pool's geological producing zone, and III^b, not III^a, is the relevant assumption. In fact, the areal extent and volume of many (but not all) pool types are highly correlated. When this is so, III^a and III^b are, in the use to which we shall put them, almost exchangeable.

Assumptions I, II, and III imply that once a play has begun the probability of discovery decreases on the average as the play unfolds. While descriptively harsh—there are plays in which the success ratio continues to rise for a time after drilling of the initial discovery well—the specific functional form for the probability of success within a play implied by I, II, and III is fairly simple and allows us to calculate an estimate of κ.

Assumptions I, II, and III describe the physical evolution of a play, given that it has begun. To articulate accurately in mathematical terms how and when a play begins is substantially more difficult, since geological knowledge generated by seismic, gravity, magnetic, and surface surveys and analysis of exploratory well data as well as costs and prices are determinants of the probability that a new play will begin at a given point on either a time scale or a scale composed of cumulative exploratory wells drilled. The spatial configuration and geographic location of sediments also play an important role. There are, nevertheless, a number of simple descriptive assertions about the genesis of a play that lead to plausible postulates about the occurrence of a new play at a given point on a scale of cumulative number of wells drilled:

(1) The cumulative number of exploratory wells drilled in the province is an index of geological knowledge.
(2) As the volume of unexplored sediment in the province decreases, so does the likelihood of a new play occurring.
(3) Exploratory wells drilled in an existing play (*intensive* wells) are less likely to lead to a new play than wells drilled in an area not contiguous to an existing play (*extensive* wells).

Cumulative number of exploratory wells drilled is at best a crude surrogate for geological knowledge. However, geological knowledge does grow as the number of wells drilled grows and so the latter is an index of the degree to which the geology of the region is understood. Assertion 3 suggests that the interarrival times between successive plays, measured on a scale of exploratory wells drilled, is on the average shorter the larger the proportion of extensive wells per well drilled. Assumption IV articulates this idea more carefully, although considerable further refinement of it is necessary before it can be used to structure a probabilistic model of interarrival times between successive plays.

IV. Interarrival times between successive plays are uncertain quantities. The mean time between two successive plays, measured on a scale of cumulative exploratory wells drilled (a) increases with an increase in the proportion of wells drilled extensively subsequent to the beginning of the first of these two plays, and (b) increases as the volume of unexplored sediment in the province decreases.

The analogue of IV for interarrival times measured on a time scale requires us to consider costs, prices, and investor behavior in the face of uncertainty; i.e., the economic returns to exploratory ventures within each subpopulation. The implications of assumptions III and IV are currently being explored and will be the subject of future reports.

SUMMARY OF DISCUSSION

Four methods were described for estimating the total number of reservoirs in a play. They are volumetric analysis, analysis of the shape of the expectation curve, probabilistic spatial analysis of reservoir deposition, and subjective probability estimates by geologists.

A question was raised concerning the application of Kaufman's model for predicting cumulative discoveries over time, as Hubbert does. Kaufman expects to derive curves roughly similar in shape to those suggested by Hubbert, but Kaufman would be reluctant to use Hubbert's curves in a model because they contain neither an economic mechanism nor a consideration of equilibrium between supply and demand.

A method was outlined for incorporating the results of the probabilistic model into an econometric model for estimating a production function for oil or gas, where oil or gas discoveries are a function of the number of wells drilled. Starting from the two postulates mentioned in the paper, and modifying postulate II to account for the knowledge gained during prior drilling, a "success ratio" is derived. This yields the functional form which is used in the econometric model to estimate the number of wells drilled per unit of time in individual plays.

The applicability of this method for estimating oil in place worldwide was explored. The method was developed to study the plays within a given basin. For estimating oil in place throughout the world, one would probably have to repeat the analysis for each basin and then sum the results across basins. An alternative to this latter step involves estimation of the distribution of the mean and variance of the log normal distribution for plays with a basin. Assumptions have to be made about these distributions because there may be little or no geological continuity among the plays. If one is willing to make such assumptions, then one can draw analogies across basins. Thus, the distribution from one basin can be used to estimate oil in place in a similar basin elsewhere.

Both these approaches involve serious data problems. Usually the type of data needed is either proprietary or very expensive to collect. The region studied in the model is unique in that the data are available and inexpensive. The paucity of data elsewhere extends to cost information for drilling and exploration. One excellent study conducted by the Federal Power Commission is unavailable. There is a great need for data akin to that of the Alberta Energy Resources Commission. Much of the data that exists among the oil companies is not made available, for two reasons. One is that secrecy prior to bidding is necessary for maintaining a competitive position. Second, there is an inbred secrecy in the oil industry regarding the extent of reserves.

The possibility of using the estimates of petroleum reserves from the Kaufman model as a constraint for energy available in a national input-output model was raised. Theoretically this is possible, but because of the data problems mentioned above, this is not now feasible.

DISCUSSION

HOFFMAN: The usual line of discussion after Gordon's interesting presentation involves the extension of these techniques to look at pools or collections of reservoirs and their distribution over the surface of the earth; to use these techniques to try to help estimate ultimate oil in places throughout the world. And later I would like to get into some of the methodological problems which might arise in doing that, introducing the notion of the different cost of investment in exploration of offshore areas, Arctic areas, as contrasted with a region like Alberta, or the Continental U.S. But before going off in that direction I don't want to neglect any questions that might have come up regarding the presentation that Gordon made. Does anyone have any questions on that?

GRIFFIN: How do you propose to estimate what N is?

KAUFMAN: There are about three methods that one can follow. One is the fairly standard method of volumetric analysis in which a geologist will come into an area like Alberta and for each of these particular zones, on the basis of regional geology and what's known from successes as well as failures, make a gross volumetric estimate of potentially producible sediments. Now, one has kind of a structural link between the total producible sediments in the mean size in the underlying population and the number of fields. Because if I think of size of reservoir in terms of volume, of oil in place divided by recovery factor, I get volume of sediment. I take N times the volume of sediment and that's total producible sediment. If you give me either N or the volume of sediment and I can estimate mu and sigma square, then I've got kind of an identification link.

The other way is to notice that the shape of the expectation curve clearly depends on what N is. I haven't been able to sort from the mathematical morass that arises from the juxtaposition of what are seemingly two very trivial simple assumptions the process by which one validly can get a maximum likelihood estimate of N. I just haven't seen it yet. It's in there someplace; there is information about the population size in that damn thing. It is not clear how to exploit it, yet. But I think we will eventually have to discover it.

Yet a third way of estimating N is to do a spatial analysis, a probablistically spatial analysis, of reservoirs deposition, such as was done by Bradley and Hewlitt. They have characterized for Alberta, in fact, the number of reservoirs per unit area as being pretty well approximated by a negative binomial distribution, and they have given the parameters for this. That gets a little bit trickier when one begins to decompose in terms of individual plays. Now, they essentially have regarded Alberta as one big play. You can start having sparse sample observations for unit area problems and so on; but in principle that kind of probablistic spatial model can be applied here also.

A fourth method would be to do the kind of thing we were talking about before; that is, to have a geologist or set of geologists who think they know what's going on out there make subjective probability estimates of N. I think what one wants to do is as we do with many of the policy models; do conditional analyses to see how things change as N changes, and how sensitive the results are to changes in N. It seems as though there are some substantial differences over wide ranges. Carry out two or three or maybe all of these methods where possible, cross-checking one against another to see what constitutes reasonable Poisson point estimates for N. Perhaps you think I am being evasive, but I can always in principle work with the probability distribution for N and crank it through numerically if not in very elegant mathematical fashion.

UTSUMI: You mentioned this is the problem A, and

later you will plot along the time scale. What kind of curves do you expect to draw?

KAUFMAN: What kind of curves do I expect to draw?

UTSUMI: Are they similar to Hubbert's curves?

KAUFMAN: I think you will probably see something like the Hubbert curves. They will not be as smooth; there will be humps and bends in them because the economic characteristics of each of these plays is clearly dependent upon the underlying physical size distribution, and upon what proportion of reservoirs you have discovered. What you are doing in a given area is simultaneously pursuing the activities in all twenty of the plays that I put up there. And the aggregation of those will give you that curve on a time scale. If you look on a time scale within a given play, I think you would get something crudely S-shaped like Hubbert's curves. It sounds very plausible you are finding the big ones first. You may increase the success ratio somewhat as you move along because of increased knowledge about the geology and other features of this particular horizon, but ultimately you get to the decline effect which gives you the s-shape. The difference is that here we have begun with a set of physical postulates, and the s-curve is coming out as a logical implication of those very basic assumptions, rather than being imposed as a mathematical ad hocery. If nothing else, it is intellectually more satisfying.

UTSUMI: But even if the total crude oil reserve was twice as much, the peak of Hubbert's curves would occur at about the same time.

KAUFMAN: You are talking about the time derivative?

UTSUMI: Yes.

KAUFMAN: Of Hubbert's curves?

UTSUMI: I am concerned about where the peak of the curves would be located.

KAUFMAN: I'm not sure I fully understand the implications of that. Let's see, you are talking on a time scale . . .

UTSUMI: Yes.

KAUFMAN: I think the maximum rate of additions to reserves would occur at the same time whether you doubled the underlying ultimate available reserves or not. I'm not sure I believe that.

HOFFMAN: Are you implying that the peak is at the same level?

UTSUMI: No, no, the level of the peak would be much higher, but the peaks would occur at about the same time.

KAUFMAN: Well, it seems to me that the whole Hubbert analysis submerges so many things below the surface in terms of economic interplay in markets, that I wonder whether it would reflect physical features of what is going on. It is very hard to know what to say about that. And I wonder, in response, if it is nothing more than simply an artifact of his having chosen this particular kind of functional form to fit to the data. The answer may be no. I mean there may be something deeper there; that's certainly a plausible hypothesis. Incidentally, a fellow by the name of J. M. Ryan wrote what I thought was a devastating and absolutely accurate critique of this, and it is well worth reading because it focuses on some of the fundamental issues relating to modeling.

HOFFMAN: Does this comment refer to Hubbert's curve for the exhaustion of resources or for his relationship between the drilling rate and discovery?

Kaufman: I thought it was the drilling rate.

HOFFMAN: That's production?

KAUFMAN: Yes.

UTSUMI: Then Hubbert's curve may become fundamental, a most basic parameter to be incorporated into the macro world energy models. I am concerned about the time when the peak will occur because that will be zero growth, no growth rate of the supply of oil.

KAUFMAN: Aren't you suspicious though of any kind of extrapolation of Hubbert's thing considering that there is virtually no economic mechanism there—no real direct consideration of equilibrium between supply and demand—no reflection of this in the modeling. I am very disturbed by that.

HOFFMAN: You can include the secondary and tertiary recovery possibility as a function of price.

UTSUMI: I am concerned about the reliability of Hubbert's curves. How can it be backed up by a mathematical probablistic theory?

HOFFMAN: Okay, I would expect something roughly of the same shape to come out.

KAUFMAN: However, it would be well worth reading Ryan's critique, and I have copies of it to distribute.

BENENSON: Gordon, you mentioned that this method you are working with could be inputted into an econometric analysis. Do you have any suggestion as to how to do this?

KAUFMAN: It seems to me we are talking at the level of technical mathematics in detail to econometric models which is a specific functional form of the decline in turn within a play or within a region of incremental additions to reserves B. And the kind of thing I showed you on the board, when blended with a model of the success ratio, would yield the functional form which should go in. I would like to say something very quickly about that. You see, if you accept this sampling without replacement in proportion to random size, if you add a purely random physical process, like throwing darts, as we showed, then the probability of success, namely, discovering a field at a given point in time in the history of exploring a given region and looking at a particular horizon could be articulated as being proportional to the size, the areal extent or volume of as yet undiscovered reservoirs within that horizon to the ratio of total volume of viable prospects for exploratory activities. In other words, you have a volume of detectable sediment that looks worth exploring, and there are only certain pockets of it that contain oil. So in a certain sense you can think of it crudely, in the first crude approximation, of randomly, if you had kind of a constant zero technology situation, throwing darts into it. Then the probability of making a discovery would vary as a function of what you have discovered and the size of what you have discovered. Think of an urn containing various colored balls. You discover a particular color and you take it all out. You have a lot of white balls mixed in there and that is not a discovery . . . you just keep sampling. Clearly, the probability of making a discovery or not making a discovery changes, but you have here a simple physical postulate about the success ratio or discovery process, and you could supplement this by putting in a technological coefficient that would make the discovery process probablistically more efficient than pure random sampling according to this process. And that is what I meant when I said that, from the point of view of pursuing different modeling approaches to the same phenomena, it certainly is worth pursuing the logical extension of the postulates that we put down here. And I am imagining that what one could come up with, after a little thought is something very much like what one gets with the logit formulation (number of successful wells that you see in McAvoy-Pindyke). In fact we have discussed this before between ourselves. and the logit formulation is the natural one that comes out in certain asymptotic approximations which come out of the postulate that I just mentioned. So, we want to put these two together. Yes, it's still rough. I am not prepared to say at this juncture precisely what you ought to do if you come up with that thing and pull it out. I guess maybe I am not brash enough, but I could give you an approximation for something like this.

HOFFMAN: Could you speculate a bit on the application of this methodology to estimating oil in place throughout the world.

KAUFMAN: Tjalling Koopmans keeps asking me this question. Gordon, why don't you just aggregate and regard each basin in the world as kind of an individual sample point? In one way that is the crudest extrapolation. My feeling is that it is just so far out of joint with the nature of the basic assumptions about the physical process that it won't work. But what would work as a crude approximation, provided that you are willing to go out and get the data, which is a tremendous job, is that you take an area like the Permean Basin and say: what the heck, let's disregard the fact that there may be 50 plays that we ought to look into individually; let's just lump them all together. Aggregate the Anodarko Basin, and the Julesberg Basin, and offshore Louisiana, and so on. Aggregate at that level, apply this methodology to make estimates; then begin to add those things up to get what the returns would be at the margin, and make estimates of the total amount that remains to be discovered. I think that could be done. I have a student now who is off to the Far East, working hard on gathering statistics for on and offshore China. And we will process those through this kind of analysis.

GRIFFIN: How many wells have been drilled out there?

KAUFMAN: I am not really sure. I will know in another couple of months.

GRIFFIN: You might have a sample of one?

KAUFMAN: No, there has been some work out there. There has been a lot of seismic shooting going on. There is a terrible data problem, and for people like ourselves, getting trustworthy data is very hard; companies are loathe to release it. If you go to an organization like Petroleum Information Services, which is capable of gathering it for you, they say: "Well, we will give you a nice estimate for offshore Louisiana reservoirs. Let's see, it will only cost $500 a reservoir for a good engineering estimate. If you want a sloppy one, maybe we will do it for 50 or 100 dollars." I have 1,096 reservoirs in Alberta. That's $50,000 just for the basic data for Alberta alone. Cheap! The commission was tremendously helpful; they sold it to me for $1,200—a portion of the well data file, the oil reserve data, and the gas reserve data. So it is an informational problem. Because, in principal, if you have the computer time and the information, you can crank through every one of these basins and put them together.

HOFFMAN: Suppose you're dealing with a basin that has different investment costs involved exploring the

different regions of that basin. A problem arises when you go to a global application of the technique. In looking at this as an investment strategy, do you plan to account for possible differences in the cost of investing in exploration?

KAUFMAN: I think you have to, absolutely. For example, to get an idea of how tenuous most of the cost figures are, I will give you a copy of something that Paul Bradley and I did that was published in the memoirs of the Arctic Geology Symposium. What we did was an economic simulation of a generic Arctic venture. When you start looking at these things in detail, you begin to discover that there is a tremendous information gap. We do not realize when we start looking at statistics of demand and supply and the manufacturing industries in areas like the domestic United States and Japan how tremendously rich and varigated the statistics and evidence that are available. I would suggest, as I was saying earlier, that this is precisely the kind of detailed micromodeling of individual ventures that has to be done before you can sensibly go to the next step. That is, how do the economics influence the rate of drilling in a particular region? You know the rate of drilling determines the success ratio and the size of discoveries as a function of these physical postulates in each play. So that there is a logical progression.

BENENSON: I am wondering about the application of that chain of reasoning to making decisions for investment in refining facilities.

KAUFMAN: Well, pipeline investments, for example, are more natural I would think than refineries because you are not going to build a pipeline where it ain't.

BENENSON: Yes.

KAUFMAN: That is one class of capital investment decision that is critically dependent upon having reasonable estimates of what may be there. On the other hand, one may argue that many of these major capital investment decisions are postponable and can be made ex post hoc because, first of all, it takes 5-8 years to develop a field. Take something like the Edson Lake gas field, one of the first big gas fields found up there. It took 5-8 years to develop it. Well, in the meantime, you say: "Gee, I have sunk a discovery well, completed and set pipe last month. I have five years, five to eight years, so I can make my decision now. I didn't have to make a decision about whether to tie into a trunk line or whether I wanted to put a processing plant there or not."

McCALL: I think that is the fundamental thing. You find it first . . . you don't have to make any of the other decisions.

GRIFFIN: How does the quality of the Texas Railroad Commission data compare with that for Alberta? Is it the next possible area? Anyone from the Texas Railroad Commission around here?

GRIFFIN: No, I don't think so . . .

KAUFMAN: Well, I have a feeling that there is very little domestic data that I really trust. Certainly you work with what you have got, and certainly the stuff coming out of the API is tremendously good material. You have a mixture of different companies with slightly different techniques putting things all together in a big mish-mosh. The one study that I think has been done on a national level, very intensive and thoroughly done, is the one that Paul Rupe supervises at the Federal Power Commission. It is done under the auspices of the national gas survey. We were going down from time to time with the Federal Power Commission. As I understand it, those figures were locked in the safe of the Commission offices and nobody but the Commissioners are allowed to look at them. I know we never got a chance to look at the figures. But, it was an excellent survey. We could use the Freedom of Information Act or something like that to get it now. In general, I think what we need at the national level is something akin to the Alberta Energy Resources Commission.

HUDSON: Would it be possible to get any mileage by placing the estimates of mu and sigma squared over there to some model giving their distributions?

KAUFMAN: That's a good observation. You are talking about superpopulation, like of parameters. About ten years ago I began to explore that with some local domestic basins. I think that the problem you get into is that you have to make some very heroic assumptions about the shape of the super-population. Of course, there are some perfectly natural assumptions that stem from the nature of the stochastic processes that you would use here, and that is namely that mu, for example, would be normal and the reciprocal of sigma squared and the super-population, one over sigma squared would be gamma.

HUDSON: Is there any sort of geological continuity that would fix you up?

KAUFMAN: That's what seems to be missing . . . in other words you don't give a set of really big acceptable physical postulates such as lead to one and two at that super-population level. But that's an interesting idea you are suggesting and it's one well worth pursuing, because it provides one way of getting at, in a crude way, worldwide statistics. Draw certain gross analogies and you say in Alberta we have a population of parameters like

this; here's an area that is fairly analogous and why not assume the same kind of thing for that.

HOFFMAN: The data problem is so central to this. Do you detect any movement or promise that this might be resolved?

KAUFMAN: I think you people are better qualified to speak than I. You are closer to the federal government.

HOFFMAN: It seems to me the energy demand model in the economic community was successful in stimulating the move toward better energy demand data. I was wondering if there was a similar snowball effect?

KAUFMAN: I will say this; I had some discussions with Michael Harrington, the Congressman from Massachusetts, who has been working on this proposal to create a national fuel corporation. I will send you some of the documentation that Harrignton sent me. One of the purposes in creating a national fuel corporation would be to loosen up the tight information policy on the part of the domestic oil companies. Well, I don't think the idea makes much sense, but that is one of the ways to get information on costs. Trustworthy information on costs and reserves were two of the things that were designed into this thing, and I don't know what is happening in Congress, but I don't think that it stands a snowballs' chance in Hell of getting very far.

HOFFMAN: Well, why is Alberta successful in getting this kind of data?

KAUFMAN: Because they legislated that allowables are based on joint determination of reserves by the crown and by the individual companies and in addition, lease-sales in Alberta are handled by the Crown, almost exclusively. Somebody has to come to them and ask them to post a property, a parcel for bid at the next public auction. You want to be honest with them because your allowables depend on it; they check back on it and keep very careful track of what is going on with every reservoir in the province. You don't lie to them too many times and get away with it. They are going to come back and haunt you . . . one way or another . . . they have many ways to get at you up there. It just seemed to work very well with very little lessening of competition. One of the big arguments that the majors make is that this is proprietary information (our reservoirs). I mean if we tell people what oil and gas in place is, that is competitive information that will lessen competition.

HOFFMAN: There is nothing like that likely to be set up in the off-shore oil programs.

KAUFMAN: Again, I am not well qualified to speak on that. I am not in close enough touch with the mechanics of the politics and governmental process to say anything sensible about it.

BENENSON: Pat McCall, I wonder whether you have a sense of a disparity between what everybody else knows about reserves and what the oil companies know about reserves.

McCALL: The position that I'm aware of is that information on oil in place, as best estimated by our experts on a really broad basis, like a total basin or maybe the total sub continent is something that, as far as I know, we have no trouble in sharing on an aggregated basis like that. But that doesn't help you.

KAUFMAN: Exactly right.

McCALL: We do have tight security on specific oil prospects, probably mostly for reasons that perhaps reach pretty far back in time.

KAUFMAN: Well, when it comes to competitive bidding, that makes absolute sense. You may recall the last big sale they had in Alaska. One syndicate had a railroad train running back and forth on a track for three days. Inside were the men going to submit the bid. Absolutely no communication from the outside world. Just running back and forth in a railroad car so that the information wouldn't leak out. As you know, it can be worth millions to know what the next syndicate which is interested in that tract is going to bid. The amounts of money left on the table are enormous in these bids. It's nothing to see an off shore bid of 12.5 million and the next bid is 1.2 million; you have left 11 million dollars lying on the table. This relates to two kinds of uncertainty: uncertainty with respect to competitor behavior and uncertainty about the value of what's there. At that juncture, secrecy is warranted, but not when talking about producing reservoirs that have already been discovered, about what you can get from secondary and tertiary recovery, about what your estimates are of oil in place using standard engineering formulas. Are you in agreement with me?

McCALL: Yes. But you're not talking to somebody who has that kind of information in his control. There's not a compelling mentality in our company or any other that I know of that would cause the top management to instruct those specialists that they're incorrect in withholding that information. It might be worth going into the type of special position that they occupy. They are our witchdoctors, our mystery people, and nobody knows exactly where oil is. They know more than the average person. But they will never promise to find oil. They will only promise to look for it.

KAUFMAN: Very well said. You can understand the exploration mentality.

McCALL: The connection between spending money on exploration and finding oil, which is the basis upon which they exist in the company and is the basis upon which the company allocates money to them, is one that they don't disclose in proposing to look for oil. They don't have to.

BENENSON: Gordon, I wanted to test one other application of the method which you presented. We have been grappling with a problem. We're trying to find some reasonable bounds for a couple of vectors in our input/output models. One of them is a gross output vector, sector by sector. We're bounding that now on the upper side by the capacity utilization ratios. Ultimately, we're going to have to do some projecting, sector by sector, of our input/output table. I'm wondering if, for the energy sectors, particularly for the oil sector, it would be possible in some way to apply your analysis to estimate a bound?

KAUFMAN: I'm not sure that I understand the connection.

BENENSON: We are faced with the problem of projecting a set of snap shots of the future, of what the economy will look like. Then we will change some of the constraints so we can see their effect on the economy. Some of the constraints are natural resources constraints, and one of them is an energy constraint which we want to make sure is reasonble. When we project this into the future and start maximizing, we don't want to exceed what seems to be a reasonable use of energy in the future. Now, what I'm wondering is whether the method that you're developing could be used to bound our possibilities so that we don't exceed what is likely in terms of utilization of natural resources.

KAUFMAN: So what you're saying is you would like to get, first of all, some gross point estimate of the availability of crude petroleum in various geographical areas of the country. Again, in principal, given the kind of finely partitioned data or evidence that we have been working with in Alberta, the answer is, yes. You can get probabilistic estimates of what remains to be discovered. In practice, I don't think that there are data sources for the major producing areas of the United States finely partitioned enough to give you the kind of information you need. There is some kind of middle ground whereby it is possible to pick out some of the ideas that are in here and impute, from whatever currently available statistics there are, what those bounds ought to be. I must admit I haven't thought carefully about that question. How these two would fit together is something that certainly bears thought. This is different than the aggregation problem.

BENENSON: We wouldn't need the kind of accuracy that is needed in trying to develop a portfolio for investment. This is a much cruder bound. But the question is, would it be better than using a capacity utilization ratio.

KAUFMAN: It's a tricky question. Could I beg off? I'd like to see some of the things that you're doing, and the way that you're estimating it now. There must be some similarity between this and the kind of thing Ken Hoffman is doing.

HOFFMAN: I'm hoping that we will get into a discussion of the similarities and dissimilarities this afternoon.

KAUFMAN: I think that certainly is an interesting question to explore, and I ought to have spent more time thinking about it, but I haven't.

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COUPLED ENERGY SYSTEM-ECONOMIC MODELS*

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SUMMARY

A coupled energy system/economic model is being developed for energy policy analysis and technology assessment. The model emphasizes technological detail of both supply and utilizing devices employed in the energy system, in terms of conversion efficiency, cost, and emissions to the environment.

The energy system model consists of the Reference Energy System format and the Brookhaven Energy System Optimization Model. These models can be used to analyze the development of the energy system, in particular the various interfuel substitution patterns which may ensue in response to constrained fuel supplies.

The following information is required in order to apply these models:

1) Level of energy demand,
2) Estimates of the availability of specific resources, measured in annual production levels, and
3) Any other constraint that may force the system to depart from overall cost optimization.

Special features of the model that are important for projecting energy supply and demand are the scope of the model in allowing for interfuel substitution, the incorporation of a load-duration curve for the electrical sector, and the inclusion of the utilizing device as an important element in interfuel substitution. The major shortcoming is the lack of regional detail.

The models incorporate the efficiencies of supply and utilizing technologies. They are employed to determine the resource demands associated with the basic energy demands specified as input. Thus, basic energy demands may be held constant while different resource demands can be estimated as fuels and technologies are substituted at different efficiencies.

The presentation dealt in detail with the methods for developing the requisite inputs mentioned above, and for operating the model. The model yields the optimal energy flows within the energy demand and resource-supply constraints that are applied for a particular analysis. Also determined is the total annual cost of service and an inventory of emissions to the environment associated with a given energy flow solution. Finally, a study is provided of the range of cost and efficiency over which given technologies are competitive. A coupling of the optimization model with an energy input-output model of the U.S. economy is in progress. This combination overcomes some of the difficulties in the conventional input-output approach by providing for technological change and interfuel substitution in the energy sector.

* * *

INTRODUCTION

The Brookhaven energy system-economic analysis techniques encompass the technological features of the energy system as well as economic and environmental factors. The energy system model is based on the Reference Energy System and the Brookhaven Energy System Optimization Model (BESOM) that has been developed and applied to energy technology assessment and studies of patterns of interfuel substitution. The coupling of this model to an input-output representation of the United States economy is in progress. These coupled models will be employed for energy-economic analysis at the national level although they can also be applied at the regional level given an appropriate regional data base. Work on the incorporation of a more sophisticated treatment of biomedical and environmental effects of the energy system is in the planning stage.

The Reference Energy System format and associated projection techniques are employed for developing energy supply-demand projections at a high level of

*Work performed under the auspices of the U.S. Atomic Energy Commission.

technological and functional disaggregation. The BESOM model provides a methodology for the detailed analysis of energy resource allocation and the energy technologies that may be employed under the influence of constraints on the availability of those resources and technologies. The usual objective in the optimization process is cost minimization; however, a variety of objectives and special constraints including environmental considerations may be reflected in the formulation of the model.

The coupling of the energy system optimization model with the input-output model overcomes certain difficulties in the conventional input-output approach by providing for technological change and interfuel substitution in the energy sector. This coupling also makes explicit the relationship between the energy demands used in the energy system model and the GNP structure represented in the final demand vector of the input-output model. The effort to couple these models is a joint program between the Energy Systems Analysis Group at Brookhaven and the University of Illinois Center for Advanced Computation.

The scope of the Brookhaven energy system-economic models, their interrelationship with supporting data bases, and applications are illustrated in figure 1. Following is a summary and definition of the elements shown in figure 1.

EMDB - Energy Model Data Base. A model independent data base including efficiency, air and water emission, and occupational hazard coefficients expressed in appropriate units per 10^{12} Btu for approximately 600 supply processes and 200 end uses

I-O - Input-Output Model

ESYG - Energy System Generator. Computer program designed to extract data from EMDB and convert to coefficients for BESOM

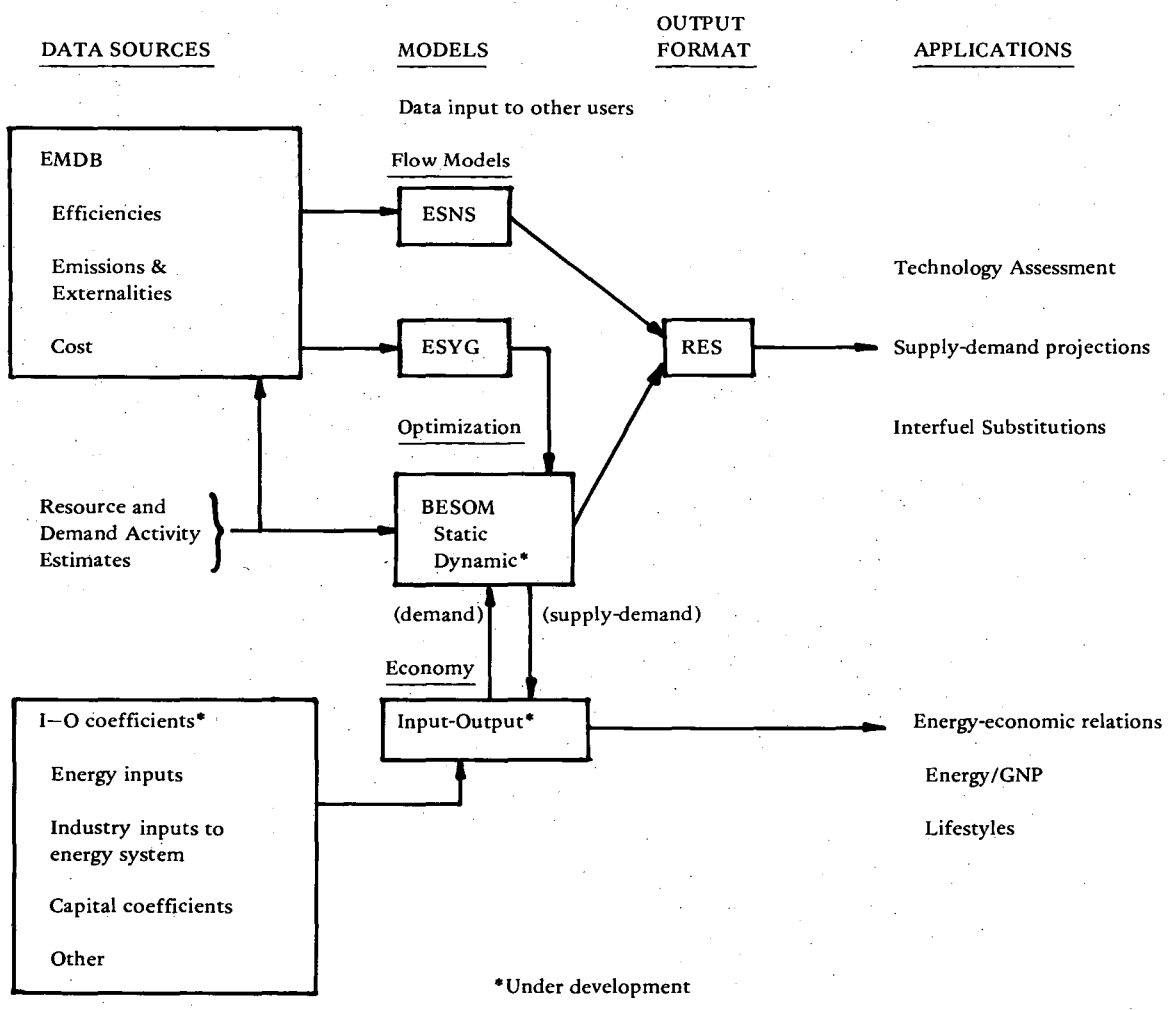

Fig. 1. Brookhaven Energy System-Economic Models

ESNS - Energy System Network Simulator. Energy Flow computer program designed to produce resource and emissions inventory in RES format using data from EMDB

BESOM- Brookhaven Energy System Optimization Model. A linear programming model for analysis of optimal supply-demand configurations.

RES - Reference Energy System. Network description of energy system including all processes from extraction through conversion and transportation to end use. Resource consumption and emissions and environmental effects inventories are included.

The following two sections of this paper deal, respectively, with descriptions of the Reference Energy System and associated projection and analytical methodologies including the otpimization model, and the Input-Output model.

REFERENCE ENERGY SYSTEM AND OPTIMIZATION MODEL

The Reference Energy System (RES) and linear programming optimization model (BESOM) include a detailed representation of energy supply and utilizing technologies. These models were designed for application to the analysis of future development of the energy system and of interfuel substitution patterns that may take place in response to constraints on the supply of indivdual fuels. A version of BESOM incoporating demand elasticities is under development and will enhance the projection capability of the model by accounting for changes in the level of demand for energy in response to price changes.

The RES and BESOM may be applied to projection of the supply-demand configuration of the energy systems given the following input information.

1. Level of energy demand activity in terms of number of households requiring space heat, passenger miles of auto and air travel, etc.
2. Estimates of the availability, in terms of annual production levels, of specific resources
3. Any other constraint that may force the system to depart from overall cost optimization, e.g. use of oil or gas as boiler fuel in urban areas because of air pollution regulations.

The RES is essentially a specialized format for representing the detailed technological structure of the energy system along with resource consumption and emissions to air and water. As such, RES's can be developed with or without the aid of a simulation or optimization model. Computerized network-type flow models have been developed at Brookhaven to construct RES's drawing on efficiency, cost, and environmental data from the Energy Model Data Base (EMDB).[1] The EMDB is available on the Brookhaven computer and includes about 600 individual supply processes and 200 end uses.

The BESOM provides an optimization technique for use in the development of RES's reflecting supply constraints their influence on interfuel substitution. The special features of this model that are important in projecting energy supply and demand are the scope of the model in allowing for substitution between the electric and non-electric sectors, the incorporation of a load-duration curve for the electric sector, and the inclusion of the utilizing device as an important element in interfuel substitution. The major shortcoming of the model at present is the lack of regional detail which may lead to somewhat different fuel use patterns based on variations in transportation cost of different energy forms.

The RES and BESOM techniques require a special type of demand specification as input. The demand is specified as a Basic Energy Demand in Btu, which is the amount of energy required to support an energy utilizing activity such as space heat, automotive propulsion, etc. assuming that the energy could be used at 100% technical efficiency. The models incorporate the efficiencies of supply and utilizing technologies and thus are employed to determine the resource demands (e.g. oil, gas, coal, electric) associated with the Basic Energy Demands that are specified as input. Thus, it is evident that Basic Energy Demands may be held constant while very different resource demands can be obtained as fuels and technologies are substituted at different efficiencies. It is common practice to use resource demand as a representation of energy demand and it would seem useful to make a distinction between the two to at least separate the components of demand that are dependent upon the level of activity of consumers from those that can be controlled by technological improvement of supply and utilizing devices. From this point on, the term energy supply-demand projection will be used to describe the type of projection developed by the RESBESOM combination.

Following is a summary of the approach used in developing the energy supply-demand projections described in AET-8 for use in the OST Assessment of Energy Technologies.[2]

For the purpose of the technology assessment it was necessary to develop projections of energy demands in a detailed, or disaggregated, manner. This approach was required in order to evaluate technologies that may apply to very specific end uses. To evaluate the use of solar energy for water heating, for example, the projected growth of this end-use must be exhibited in the reference system along with the technologies that can compete to satisfy that end-use.

It is recognized that projections made in this disaggregated manner may well underestimate the total energy demand in the future because of unanticipated new uses of energy. Since the technologies employed for such uses obviously cannot be defined, it is not, in general, necessary to reflect these uses in the reference systems. It is felt, however, that such demands are more likely to involve electrical energy than other energy forms and, to reflect the impact of these demands on the supply systems, several undefined electrical demands have been included in the residential and commercial miscellaneous electric categories (by postulating phantom appliances and demands), and in the demand category for industrial miscellaneous process heat.

Before describing the methodology used to develop the projections it is useful to define several parameters. These are:

1. Fuel Demand, D_i = The quantity of a fuel*, i, actually consumed in a specific demand category, such as space heating, automotive transport, or aluminum production.
2. Total Fuel Demand, D = the total fuel required to satisfy the requirements of a specific demand category. Electricity is considered as a fuel in this sense and D = $D = \sum_i D_i$.
3. Relative Effectiveness, e_i = the relative effectiveness with which fuel, i, is used in a demand category. This parameter depends on the utilization technology employed. See discussion in Section II
4. Basic Energy Demand, E = the amount of energy that would be required in a specific demand category, assuming a relative effectiveness, e_i of 100% for each fuel employed. Thus, for a given demand category where quantities of fuels, D_i, are consumed with actual Relative Effectiveness, e_i, $E = \sum_i e_i D_i$. Implicit in this definition is a specification of the utilization system, e.g. size of car or housing mix between single family and multifamily dwellings.
5. Degree of Saturation, S = the fraction of the potential demand for a particular energy use actually being fulfilled at a given time. For example, if 95% of all households have refrigerators, and potentially all houses can have one refrigerator, S = 0.95.
6. Saturated Basic Energy Demand is the Basic Energy Demand that would exist in a category if there was 100% saturation, = E/S.
7. Unit Basic Energy Demand, E_u = the Basic Energy Demand per unit (e.g. per household, per lb of Al produced, etc.).
8. Fuel Fraction, f_i = fraction of the Saturated Basic Energy Demand that is satisfied by using the i'th fuel.

$$f_i = \frac{e_i D_i}{E/S} \quad \text{and} \quad \sum_i f_i = S$$

The procedure for developing a fuel mix projection in a given demand category begins with the definition of the current fuel mix. 1969 was used as the base year in developing the projection given in AET-8. The 1969 D_i are derived in most instances from 1968 data given in reference (3), escalated by one year. The Relative Effectiveness, e_i, with which each fuel is used is generally obtained from the same source and, on the basis of this information, the 1969 Basic Energy Demand is derived for each demand category.

The Basic Energy Demand derived in this manner is independent of the fuels employed to satisfy the demand, and is projected into the future on the basis outlined for each demand category in Table I, including any increased saturation that may be postulated. In categories where a unit basic demand is defined, it is used as the basis for the projection and, in most cases, is held constant over all reference years. By specifying the Fuel Fractions, f_i, and Relative Effectivenesses, E_i, the Fuel Demands D_i are derived from the basic energy demands for each future reference year. Thus the fuel mix is defined.

Table I. Basis for projection of demand activity levels.

Sector: Category	Escalation based on
Residential:	
All	No. of households
Commercial:	
All	Proportion to residential
Industry:	
Cement	Last 10 yr. growth rate
Aluminum	Independent projection to 2000
Iron	Independent projection to 2000
Steel	AUI projection
Petrochemical	Last 10 yr. growth after 1985
Process Heat	Last 10 yr. growth rate
Electric Drive	Last 10 yr. growth rate
Transportation:	
Automotive	Independent projection to 1990
Bus	Independent projection to 1990
Truck	Constant fraction of automotive
Rail	Independent projection to 1990
Air	Independent projection to 1990
Ships	AUI estimates

*"fuel" as used in this sense includes electricity.

The specific assumptions that were made in the space heat demand category and the basis for the projection in each case are described on Table II.

Limited use of the linear programming optimization model was made in developing the projections in AET-8. The model was subsequently applied rather extensively to analyze perturbation to the projected RES's as a result of the introduction of new technologies or constraints on oil imports that forced substitution of other energy forms. The aggregated energy resource demand projection that

Table II. Projected fuel mix for Residential Sector, Space Heat Category (from Ref. (2), page A-4).

	1969			1977			1985			2000			2020		
	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i
DIRECT FUEL USE															
Methane	.529	.75	3.352	.50	.77	3.524	.43	.79	3.401	.36	.81	3.556	.36	.82	4.965
Jet fuel															
Gasoline															
Distillete oil	.410	.63	3.096	.39	.65	3.256	.33	.66	3.124	.29	.68	3.412	.29	.69	4.753
Residual oil															
Coal															
ELECTRICITY	.061	1.56	0.184	.11	1.58	.378	.24	1.58	.949	.35	1.58	1.772	.35	1.58	2.505
TOTAL FUEL DEMAND, D, 10^{15} Btu			6.632			7.158			7.474			8.740			12.223
BASIS, 10^6 households		61.805			70.543			81.207			104.0			147.0	
SATURATION, S		1.00			1.00			1.00			1.00			1.00	
BASIC ENERGY DEMAND, E, 10^{15} Btu			4.755			5.427			6.748			8.001			11.309
UNIT BASIC ENERGY DEMAND, E_u, 10^6 Btu(t)/household		76.935			76.935			76.935			76.935			76.935	

REFERENCE TECHNOLOGIES: Burner devices for fossil fuels, electric resistance heat.

DATA SOURCES:

D_i (for (1969): Ref. (3), p. 42, escalated to 1969 at the 1967-1968 growth rate.

e_i : Taken from Ref. (3), p. 18 for fossil fuels in 1969. The efficiencies of fossil fuel utilization are increased over time assuming improved insulation to reduce the heat loss in an average home by 33%. (see President's Energy Message June 4, 1971, p. 9). The fraction of gas or oil-heated homes assumed to have this improved insulation in 1977, 1985, 2000, and 2020 are, respectively, 5%, 10%, 15%, and 20%. The efficiency of electric heat is an apparent effectiveness relative to other fuels based on 1968 data given in Ref. (3), p. 42, and is held constant over time.

f_i (for 1969): These are apparent fractions based on 1969 D_i and e_i.

BASIS OF PROJECTION: The basis demand derived for 1969 is escalated in proportion to the number of households indicated by the Series 2 household projections given in Ref. (4), p. 37, extrapolated to the year 2020.

The electric heat energy demand is taken as 1.67 times the residential air-conditioning demand in 1985, 2000, and 2020. This assumes that a balanced summer and winter peak demand condition is achieved by using regional transmission interties to the extent required. (The factor of 1.67 is the approximate ratio of the durations of the heating and cooling seasons.) Gas and oil are held in the same relative proportions as in 1969.

was developed for the OST assessment is shown in Figure 2. The assumption behind this projection include no constraints on oil imports or power plant siting and only minor changes in the price of energy relative to other commodities and factors of production.

The linear programming model of the U. S. energy system[4] includes provision for the full range of interfuel substitution, including substitution between electric and non-electric energy forms. It encompasses the entire energy system including all resources and demand sectors as shown in the Reference Energy System, Figure 3. Since the range of interfuel substitutability that is feasible depends on the supply and utilization technologies that are available, the model includes the characteristics of these technologies. The technology related parameters that appear explicitly in the model are the efficiencies of energy conversion, delivery, and utilization devices; the emissions produced by the devices; and their cost. The intent in establishing the scope of the model was to include the technical elements that are of major importance in a framework that is as simple as possible. Simplicity is a requirement if all assumptions are to be evident and the results easily interpreted.

The Reference Energy System shown in Figure 3 is quantified with a set of projected energy flows for the

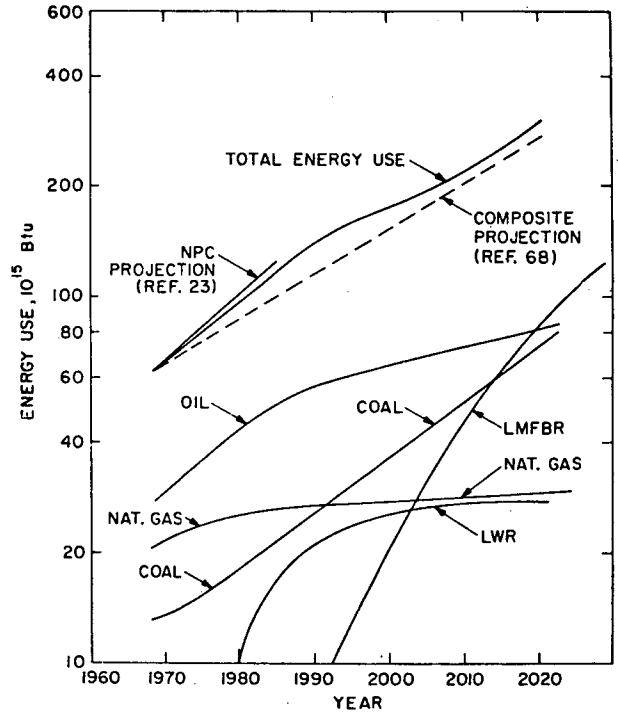

Fig. 2. Reference projections for fuel uses and total energy use. (Source: Ref. 2, p. 81)

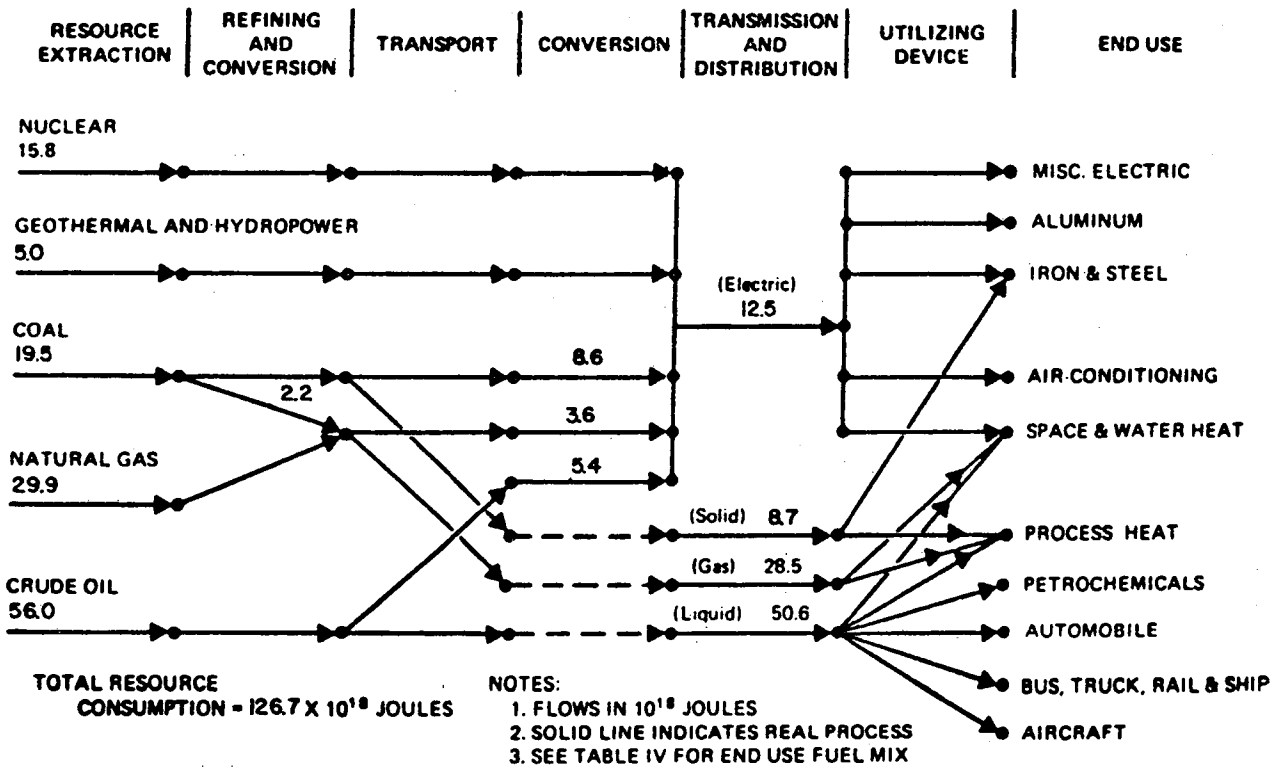

Fig. 3. Energy system network (1985)

year 1985 from alternate resources through the various energy conversion and delivery activities to specific end uses. Each link in the network represents a process or mix of processes used for a given activity, such as the refining of crude oil. Cost, efficiency and emission coefficients may be associated with each link. The energy flows indicated in Figure 3 reflect the technical efficiencies of the individual processes and thus the flows decrease progressively through the network. The projected energy flows correspond to several projections that had been prepared earlier (2,5) to indicate the degree of reliance on imported fuels that might result unless action were taken to move toward self-sufficiency. This projection has been used in several studies as a point of departure for the development of alternative configurations. The links shown in the network diagram reflect only existing technologies. Using the linear programming model, alternative energy flows may be determined which employ new technologies and which also involve the substitution of domestic resources to replace imported oil and gas.

The model determines the optimal energy flows within the energy demand and resource supply constraints that are applied for a particular analysis. The output of the analysis includes the total annual cost of service and an inventory of emissions to the environment associated with a given energy flow solution. Examination of the energy demand sectors at the right-hand side of the network indicates the degree of disaggregation included in the analysis. The substitution possibilities are dependent on these functional end uses and are quite different between the air-conditioning, automotive, and process heat categories, for example. The load-duration structure of electrical demands is also reflected in the model since the type of electric generating equipment employed is dependent on the portion of the load curve that it is to operate on. This is an important consideration in substituting electric energy for other fuels in such categories as space heating and transportation where there are significant peak demands.

The optimization of the energy system is performed with respect to cost and the objective is to minimize the cost of service, subject to policy, economic, and other constraints that may be represented in the objective function and constraint equations. Amortized capital costs, fuel costs, and other operating costs are included. A fixed charge rate of 15% is used for capital costs. Additional constraints are included to reflect existing systems that would not be replaced and to specify certain fuel uses that will probably occur for special reasons, such as regional viability, that are not reflected in an overall cost optimization of the U. S. energy system.

The linear programming methodology is rich in economic interpretation. Of particular interest is the marginal value or "shadow price" of scarce resources in a given solution. These represent the unit change in overall cost of the system resulting from a unit change in availability of given resources. They are dependent on the cost differential between the scarce resource and a more costly but abundant substitute as well as on the relative technical efficiencies of the alternatives. The shadow prices provide a measure of the economic equilibrium of the system in terms of a comparison of the cost of expanding capacity of a given type with the value of that additional capacity. They may also be used to assess the structural changes that might occur in response to changes in economic values assumed in a given analysis. The output for a given analysis also provides an extensive study of the range of cost and efficiency over which given technologies are competitive.

INPUT-OUTPUT MODEL

A special version of the energy Input-Output model constructed at the University of Illinois Center for Advanced Computation is under development to allow coupling this detailed model of the overall economy with the energy system model, BESOM.

The coupled Energy System/Input-Output model will be used primarily as an analytical technique to investigate the impact of alternative energy systems on industrial requirements. The coupled models also provide a means of developing energy demand projections that are internally consistent with a projection of vector of final demands for the Input-Output (I-O) model that represent GNP.

A matrix for the Input-Output model is shown schematically in Table III. The matrix is partitioned into four input and output sectors. R represents resource supplies, S represents secondary energy forms (electricity, hydrogen, etc.), P represents Energy Products or Basic Energy Demands (space heat, lighting, process heat, etc.) and I represents industrial sectors.

The development procedure to be followed involves extracting the energy technological coefficients from the current 365 sector I-O model[6] and the expression of energy inputs in the I-O model in terms of Basic Energy Demands which are independent of the fuel form. The fuel mix used to satisfy those demands will then be determined by the BESOM. Energy supply-demand coefficients are also incorporated in the I-O model and represent fuel allocations determined by the BESOM. The sequence in performing an analysis with the coupled model is as follows:

1. Develop projected final demand vector for the I-O model representing GNP.
2. Insert approximate energy supply-demand coefficients in I-O model (A_{RS} and A_{SP}).

Table III. Structure of input-output model for coupling with energy model.

"A" matrix:

	R	S	P	I
R	O	A_{RS}	O	O
S	O	O	A_{SP}	O
P	A_{PR}	A_{PS}	O	A_{PI}
I	A_{IR}	A_{IS}	O	A_{II}

Terminology

R = Primary energy resource

S = Secondary energy form

P = Energy Product (or Basic Energy Demand)

I = Industry flows

3. Run I-O model to determine Basic Energy Demands, or Energy Products, associated with GNP projections.

4. Run BESOM with Basic Energy Demands as inputs to determine energy supply-demand configuration.

5. Convert BESOM output to energy supply-demand coefficients for I-O and insert these into I-O model.

6. Perform iterative run and test for convergence of Basic Energy Demands.

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SUMMARY OF DISCUSSION

The question was raised as to whether the model can be adapted to permit the input-output coefficients to change when prices change, as the Hudson-Jorgenson model does. Hoffman's response was that this mechanism could not now be built into a model disaggregated to 360 sectors but may be possible at a more aggregated level.

The model is being made dynamic in that a cost function will be minimized simultaneously over several successive time periods; however, it is not dynamic in its treatment of the interaction of supply and demand. The inclusion of supply and demand elasticities would improve the model by making it responsive to price changes. Hoffman suggested using the supply elasticity variables as input to the resource constraint equations and using the demand elasticity variables in the demand constraint equations. It was suggested that the model include demand constraints which depend upon prices in previous periods as well as on prices in the current period. This would take into account a delayed response by consumers to changing prices.

A question was raised concerning the method for incorporation of demand elasticities into the constraints of the input-output model; this question was not resolved. Also posed was the question of the validity of using elasticity estimates made for a particular set of prices when prices have in fact shifted beyond the range for which the original estimates were made. The problem can be handled by defining the demand curve over a large enough range to cover all price variations; a piecewise linear representation of the demand curve may be used to accomplish this. The incorporation of elasticities into the model would involve the use of either quadratic programming or an iterative method. This is fairly straightforward in the single time period model, but would be complicated in the dynamic multi-period model because it is so large. Although the model does include an association between reference prices and

"reference demands," the latter are really hypothesized levels of consumption rather than demand.

A brief description of the input-output model operating at LBL was given. A 97-sector input-output model is being used to analyze the impacts of energy shortages on the U.S. economy. The model includes data on energy use and on employment in each industry. In a linear program, gross national product is maximized subject to constraints on gross outputs, fuel demands, and energy consumption. As each energy sector is independently constrained more and more severely, the impact of this constraint on GNP and employment by sector can be observed.

There is a need to blend detailed technological information with a broadly based economic model. This provides a tool for dealing with both technology assessment issues and economic policy questions within a consistent framework.

In the energy system model operating at Brookhaven, pollution and environmental degradation are estimated through the use of emission coefficients. However, these factors are not included in the objective function. In order to include these factors in an objective function, further work must be done to relate emission sources to ambient air quality, and to relate ambient air quality to direct social cost.

In technology assessment, another factor difficult to quantify is the probability that advance will be made in a particular technology, and further to evaluate its feasibility relative to competing technologies. Although it is difficult to obtain, this information would be useful for planning R & D expenditure.

DISCUSSION

KAUFMAN: Are you planning on interfacing the input-output data and the programming model to use some of the kind of tricks Dale Jorengson is using to get input-output coefficients as essentially internally determined by demand levels?

HOFFMAN: That's beyond the scope of our efforts now, but we'd be very anxious to apply that technique. I'm not sure that we can build it at the 360 sector level of disaggregation, and, in fact, probably we can't. I think we would want to pursue with them the possibility of coming down to some more aggregated level and projecting coefficients in the fashion that they've used.

KAUFMAN: I have another question that I guess you've answered before in various ways. It has to do with the structure of models of this kind that essentially posit future demand scenarios, so they are dynamic only in the sense that they are solved to minimize cost functions over time periods with interactions between time periods. Is that right?

HOFFMAN: Well, that's the dynamic model that is under development. The static model and the link with the I/O would be a single point optimization, but our dynamic model would be optimized simultaneously over a number of time periods.

KAUFMAN: The other thing that needs to be taken into account in interpretating the results of your model and Nordhouse's model is that this is a different kind of dynamics than the dynamics of supply and demand and price in the marketplace. Now, one can envisage a dynamic market equilibrium taking place.

HOFFMAN: Yes, it's a different use of the dynamic context.

KAUFMAN: I'd like to get some comments from you on what the meaning of the difference is and on what the empirical implications are in terms of mixes of alternate energy technology. Can you speculate about what differences you might see, if any, if you somehow had a telephone line to the Lord and He told you how to go about building a complicated, dynamic model of that kind? This is a question of the robustness of the results.

HOFFMAN: We don't plan to at the moment, but if we did incorporate the elasticity variables in what I call the time dependent or time "dynamic" model, we would come closer to the economic dynamic interactions.

KAUFMAN: You have those demands fixed out there.

HOFFMAN: Well, then they wouldn't be fixed. They would change in response to price.

KAUFMAN: Okay. You've got one set of models in which the demand is fixed . . .

HOFFMAN: That's right.

KAUFMAN: And another one with price responsiveness. How robust are these darned things? Does it really make a difference? What's your guess?

HOFFMAN: I think they do. Now you ask which simulates the future data. We considered at one time a step-wise determination of the mix of plants where you optimize in a series of steps, and, at each step, you take the best look ahead you can at the future course of fuel prices and then make an investment decision. Now that's very different from the concept of optimizing all time periods in one step. I think that there would be a difference with the former giving a better simulation about how decisions really get made. But, I think the inclusion of the elasticity variables is important in both the static and dynamic versions.

KAUFMAN: With this dynamic version, are you planning to do something like a complete optimal cost-solution via backward induction? For example, in linear programming, since you have this dynamic interacting, shifting . . .

HOFFMAN: No, it is a single step linear programming optimization. It doens't involve dynamic programming.

KAUFMAN: One way or another, there will be a myopic, essentially one period look ahead?

HOFFMAN: Simultaneously we optimize over all of these periods. There might be eight 2-3 year periods in the first step, then maybe a couple of 5 year periods, and maybe a couple of ten year periods out to the horizon.

KAUFMAN: I'm confused about the way supply and demand are interacting.

HOFFMAN: Well, there is a demand specified at each period. Starting with our point estimates of demands, we trace out the curve and then they go in as the demand constraints at each time period. If we put them in without elasticity variables, they will represent fixed demands to be satisfied and that's now a time dynamic model but not an economic equilibrium model. Now, if we put demand and supply elasticity variables in there, we've captured the economic equilibrium, I believe. But still, when you couple that with an input-output model, and you try to predict the substitutions that take place in the final GNP demand vector in response to energy price changes, you have still another problem. We're thinking some about it but not worrying about it too much at the moment. I think econometric techniques might be of value.

UTSUMI: Your optimum solution affects the demand predictions which have been used for the previous optimization?

HOFFMAN: In the static model?

UTSUMI: Yes.

HOFFMAN: Our optimization is based on the supply and demand vectors we project for input to that analysis.

UTSUMI: For the next time span, will you be changing the demand according to your optimum solution?

HOFFMAN: You're describing a sequential process where you optimize one time period and then jump ahead to the next time period and optimize this on the growth of demand. This is not the way that it will be done. The single large dynamic (on time phased) LP will essentially optimize simultaneously the full supply and demand matrix including every one of the time periods. So the objective function and the cost coefficients will be there for the first period. Then, we'll put either the same coefficients in or revise the cost coefficients with a discount rate applied to them for other time periods. There will be an overall resource constraint, supply and demand constraints for each time period, and other constraints for each time period. Now the supply constraints would represent, say, the amount of capacity you think could be installed in LMFBR's in any given time period. It might turn out that the solution wouldn't reach that constraint in one time period, but might want to go to the full constraint value in the next time period. That can't be allowed, so there have to be some intertemporal constraints that prevent that from happening. If it doesn't get installed at a certain level in the earlier time period, the amount of that capacity installed in the next time period has to be related to the amount installed previously. It can't immediately jump to the maximum constraint that you set in, assuming some orderly build up to that supply technology. In effect, it is continually looking back and forth, cycling from corner to corner and coming up with a global optimum solution for that whole time frame.

UTSUMI: Then the price equations will be fixed.

HOFFMAN: Well, reasonably fixed, but then also there will be a total oil resource constraint equation that constrains the total amount of that oil resource used in all time periods. There's where we want to put our supply elasticity variables. We want the quantity of oil produced over that time period to change in response to price changes of competing resources. I think we can capture that by putting elasticities in the overall resource constraint equations as well as in the demand constraint equations.

McCALL: How do you handle energy imports?

HOFFMAN: We'll have a sector defined as imports which we'll probably price marginally higher than the domestic production.

McCALL: Will it be constrained?

HOFFMAN: Yes, but with very arbitrary constraints. The picture of the rest of the world in competing demands is all wrapped up in those constraints.

GRIFFIN: How much trouble would it be, for example, in your demand constraints in the last period to allow that demand constraint to depend upon prices in previous periods as well as the current period? Can you still put it in this framework if you do that? That would be a truly dynamic demand constraint.

HOFFMAN: I wonder, might it be captured by the inclusion of the supply function here . . .

GRIFFIN: No, No – that's not so.

HOFFMAN: Oh, the demand constraint equation?

GRIFFIN: Yes. That quantity is a function not only of the prices in that period, but of prices in the previous periods.

HOFFMAN: We use the marginal cost of serving that demand sector in that period as the basis for the demand constraint.

GRIFFIN: As well as previous periods . . .

HOFFMAN: No, but the marginal cost of satisfying a demand depends on the point you're on on the supply curve for the total resources. This supply curve is affecting the shadow price on that demand constraint equation.

GRIFFIN: So, you're telling me that the shadow prices then would be the same in every period?

HOFFMAN: Not necessarily. The discounting, of course, would change them, as would technological change between time periods.

GRIFFIN: Yes, but I mean very systematically. Well, it's probably not worth pursuing any further. It's just something that struck me.

HOFFMAN: I think it is worth pursuing further, but I'm not sure we can do much about it here. There is also the problem of the way it responds. I guess that's what you're trying to get at. You have to capture the replacement characteristics of the utilizing technology in the demand sectors.

BREEN: Do you have a mechanism to adjust the shadow prices or the efficiency prices for those sectors that are regulated, for instance, utility industries, to adjust them to the regulated prices in the industry?

HOFFMAN: We can put tax penalties or subsidies in to project the coefficients.

BREEN: If you don't adjust them you are implying some kind of open free market and the ability to come into equilibrium with supply and demand.

HOFFMAN: I think you can incorporate those into the projected coefficients.

BENENSON: Right now, Ken, as I understand it, the model is not responsive to price. Is that right?

HOFFMAN: That's right. It is responsive in terms of substituting other resources. To that basic energy demand, it's not responsive to price. We get around that with the incorporation of elasticities.

BENENSON: I'm curious about the elasticities. Are you going to talk about incorporating them?

HOFFMAN: About how we incorporated them? Yes, I think I can recall part of the construction.

BENENSON: I'm not sure how you considered estimating elasticities, but suppose you had been doing this work a couple of years ago, and you estimated the elasticities over a range of observed prices.

HOFFMAN: We're not addressing the estimation of the elasticities. We're going to use the best estimate that experts can give us. Probably something like 0.2 or 0.3. I'm talking of the methodological problems of allowing for the representation of elasticity.

BENENSON: Okay. I'm interested in that, but what I want to get at is that suppose it was estimated for a set of prices which don't obtain during this time period. Say you have a displacement. What does that do to this system if you incorporate those estimates?

HOFFMAN: We try to define the demand curve over a range large enough. We can use a piecewise linear representation of the demand curve to cover those variations. This will reflect a set of reference demands and reference prices for each demand category in the model. This appeared to be a problem to me a couple or six months ago. We had reference demands, but we didn't have the foggiest notion of what kind of reference prices to associate with them. We just didn't have that information. But now that I see the close agreement between our projection and the DRI projection, I think we have

a set of prices to associate with these reference demands. We can represent a utility function by using the integral under the demand curve as the representation of the change in utility as you move along the curve. This utility curve can be approximated by a piecewise linear curve. This determines the coefficients that we will put on the elasticity variables in the demand equations. If the marginal cost of serving a particular sector increases, it becomes optimal to move back on the demand curve and reduce the demand by some appropriate quantity represented by the value of that slack variable. You can conceive of dropping demand as the marginal price increases from the reference point. In an alternate approach, if the marginal price of serving that demand exceeds that reference price, it's optimal to introduce a slack variable and effectively reduce the demand by some increment. That's essentially the way we do it. We don't really represent a piecewise linear demand curve. It turns out to be a step function. We're looking at techniques for getting around this step response or at least using a step-wise function that gets closer to a straight line.

BENENSON: Well, the step form seems to represent more closely what is actually occuring: that is, a lack of response over a certain price range.

HOFFMAN: But where's the evidence that that is really the way it works?

BENENSON: I don't know that.

HOFFMAN: Well, that's a minor problem. I believe that you can use a piecewise linear function with quadratic programming. Another alternative is to use linear programming and solve for the supply and demand equilibrium using an iterative technique. With this method you would use estimated supply and demand curves. On the first iteration you would use the reference demand and supply levels and solve the LP. On the basis of the marginal costs, a new set of demand and supply constraints would be specified and the LP again solved. This iterative procedure would be repeated until the new supply and demand constraints were within some convergence limit, say ± 3% variation from the previous levels. That's probably close enough, and I think that's the way we'll handle it. It will probably work alright in our single time-period model but will be much more difficult in the time dynamic model because it's so large. There, I think, we'll probably have to live with a rough estimation of demand elasticities.

UTSUMI: This small block in the matrix represents a one time snapshot.

HOFFMAN: Right.

UTSUMI: The right hand side column of cost corrections can also be time adjusted corresponding to the present time background.

HOFFMAN: Right. Then they can be changed in addition to applying a time discount.

UTSUMI: Then, couldn't you do predicting first, such as the right-hand side column of numbers as a time horizon, and price, again with a time duration? Then you can stop the calculation when you come to the five year period which corresponds to the next time block.

HOFFMAN: The solution doesn't proceed sequentially through these blocks. Its not introducing a change in variables at any point in this whole matrix. It does not start at one end and gradually work toward the other. It just operates in a normal fashion in changing the basis at random points throughout the matrix.

UTSUMI: If you have twenty small blocks, then there are many zeros.

HOFFMAN: Right.

UTSUMI: So if you do it timewise sequentially according to the LP, then you may avoid it.

HOFFMAN: Well, there are decomposition algorithms which you can apply to this class of problems. I've been talking with George Dantzig and others at the International Institute for Applied Systems Analysis and at Stanford. We have hired a fellow who worked with Allen Manne and George Dantzig at Stanford to help us with that part of the problem. Peter, I wonder if we may discuss a bit at least your plans for your input-output work in areas where it might be useful to cross check our results?

BENENSON: Okay, I'll take five minutes for an overall discussion. At this point, we're working with an input-output model that is at the 97 sector level of disaggregation. We have five energy sectors underlying the model. We're interested at this point in looking at the consequences of energy shortages, so we are casting it in linear programming format, then constraining various energy sectors, and looking at the impacts on gross output and final demand. There are several applications that we're interested in getting into. For one thing, we're interested in looking at it in much finer detail. We're also interested in disaggregating the energy sectors much further.

HOFFMAN: Further than five?

BENENSON: Further than five. Yes. There were other studies done here linking this basic input-output table to a predictive model for employment so that we may link energy, and particularly an energy shortage, to its consequences for gross output and then to consequences on employment by industry and by occupation. We're not talking about one employment row in the matrix. We're talking about an employment picture for each industry.

HOFFMAN: These are employment coefficients that you've estimated?

BENENSON: Yes, by regression analysis.

HOFFMAN: I guess Hannon has a set of employment coefficients, doesn't he?

BENENSON: You are talking about the one row, is that right?

HOFFMAN: Yes.

BENENSON: This is a different sort of thing. I guess you could look at it as a set of regressions that surround the input-output table.

HOFFMAN: Then you put those coefficients into an employment row in the I-O matrix?

BENENSON: No. It is not directly incorporated into the I-O table. Several things we wish to work on, but are not yet funded, are a dynamic input-output model and a process analysis model. That may come about rather soon. Ed, I'm interested to hear what you have to say about input-output models. You're working with a much greater degree of aggregation than we are, and it will be interesting to see how we can combine them. Your model deals with interfuel substitution and we don't have that. So I think that's another possibility for combination. We're in a very preliminary stage with this. In fact, we just got the first successful runs yesterday, successful in terms of a computer standpoint, but not necessarily successful in terms of making any economic sense. So we've got some more work to do. We're trying to get appropriate constraints that make sense for the whole system and see what various numbers look like rather than being arbitrary. I think that's about all the time I want to spend in this conference talking about it. Basically, we have several interesting inputs: Energy, manpower, and water—the consequences of which we can trace through the input-output table.

HOFFMAN: Bechtel has developed a set of coefficients. I think that the coefficients may be of a proprietory nature but the results, of course, will be available to everybody. If somehow we can get some of those coefficients, they cover manpower, construction labor, skilled and unskilled manual labor, and engineering manpower associated with the construction and operation of various plants and types of refineries, and the capital requirements for construction. They also have materials requirements in terms of structural steel, concrete, piping, etc.—five material categories associated with each type of energy facility. They don't cover water as yet but they may get into that in Phase II.

BENENSON: Actually, I had a call from them yesterday.

HOFFMAN: Yes, I saw them Wednesday and told them that you would be interested in talking with them. There does seem to be a lot of momentum building now to gather this sort of information and more efforts made to share and prepare it.

BENENSON: The kind of thing that I would really be interested in is some sort of combination with the more refined regression analyses that are done, and also with something like what Gordon was talking about.

McCALL: Would you still class your structure, as you elaborate and extend it, as primarily for technology assessment?

HOFFMAN: That is our interest in developing it. It's clear that to assess technologies, one needs a methodology that considers the characteristics of technology in great detail. But we are interested in embedding this and doing it in a context that has some relationship to the economic policy questions. I think that's an important consideration in technology assessment. On the other hand, I think the models that are more aggregated and designed for economic policy questions, benefit from some loose, perhaps, interconnection with a technological model of the energy system.

UTSUMI: Does the technology assessment include negative factors in the I-O table?

HOFFMAN: Include what?

UTSUMI: Negative factors such as pollution and environmental degradiation.

HOFFMAN: Well, the emission coefficients are included in the energy system model that is combined in a single LP with the model.

BAUGHMAN: Are those effluents incorporated in the objective functions?

HOFFMAN: No.

BAUGHMAN: They just come as a by-product?

HOFFMAN: That's right. Right now we treat them to develop an emissions inventory.

BAUGHMAN: It's pretty difficult to interpret them as something meaningful. Did you have that experience?

HOFFMAN: Yes. Exhibiting them in that way is better than having no information on them at all. If you come up with a set of technologies that reduce all emissions without increasing any, you know you're better off. But what the usual trend is finding is that what you've done is to shift emissions. You've decreased the area source emissions and increased the point source emissions. It's not very easy to make a judgment on the air quality impact of that shift. There is much work being done now in each state that uses the implementation planning program to relate emissions sources to ambient air quality. That's the first part of the job. I think more refinement is needed there. The second part is even more difficult: to relate the ambient air quality to the direct social cost. There are people who would go out on a limb and quantify these things. To the extent that data are available, we can put them into the objective function. What we're waiting for is to get a complete enough listing of even some of the poor estimates that have been made and make a trial run incorporating those directly into the objective function.

BAUGHMAN: Is this still at the national level?

HOFFMAN: Still at the national level.

BAUGHMAN: That makes it even more difficult.

HOFFMAN: Right.

BAUGHMAN: You indicate that one prime interest in using this is for technology assessment. Of course there are two sides to technology assessment. One is a calculation of the benefits of having that particular technology around at a certain time. The other one is assessing from the engineering point of view the probability that the technological advances will be made, and evaluating these in the economic framework, along with the other portfolio of projects that could also be funded. I was wondering if you were doing anything on that side or whether you were focusing more on the benefits.

HOFFMAN: We're focusing more on the benefits. I am interested in the description that Fred Zerhoot gave and that you hinted at in some of the work you are doing. I think some of that work does pertain to that question.

BAUGHMAN: I don't know if it pertains directly to that particular part of it. I guess there has been experience in trying to apply some portfolio type idea to technology assessment. I'm not too familiar with that.

HOFFMAN: We made a couple of attempts at that in structuring the kind of information that we had the panel work on for the development of the $10 Billion R and D plan. In particular, the AEC asked for estimates of the date of success and the technological characteristics as a function of the level of R and D expenditure and probability statements regarding the probability of success. It's just impossible to get estimates in that fashion on that consistent basis.

BAUGHMAN: So basically, you view your role in this as supplying the information on the benefits. Where the actual assessment of probabilities and so forth takes place is in the political arena?

HOFFMAN: We're willing to make judgments regarding the probability of success and the likelihood of various implementation rates, and I think we're as qualified as anyone to make such judgments. We do that. We've gotten estimates of these developed by the technical panels, that we thought were terribly unrealistic and we modified them. Others might consider our estimates unrealistic. We do make those judgments based on our technical experience, and I think collectively we're as competent as any group to do that.

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ENERGY POLICY AND ECONOMIC GROWTH

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SUMMARY

Hudson's approach to analyzing energy developments and energy-nonenergy economic relationships involves the use of four elements:

1) an interindustry model of the U.S. economy, incorporating nine intermediate sectors, with emphasis on the energy-producing sectors,
2) econometric models of producer behavior for each of the domestic producing sectors,
3) a macro-econometric growth model,
4) sub-models of personal consumption expenditures and of investment, government and export components of final demand.

Prices of domestic availability of output and the input-output coefficients in the production of this output are endogenous functions, simultaneously determined within the producer behavior models. Output prices and production structure reflect producer adjustment to the prevailing set of prices of the products of all sectors and of capital, labor and competing imports. These adjustment possibilities are constrained by production relationships represented by econometrically estimated translog price possibility frontiers. Thus the producer sub-models incorporate the effect of energy prices on the level and composition of energy use in each producing sector, and permit intra-energy substitutions and the substitutions and complementarities between energy, capital, labor and materials inputs to be analyzed. Final demands for each commodity are also functions of prices, permitting intra-energy substitutions and energy-nonenergy interactions to be incorporated. The interaction of the entire production-final demand nexus is analyzed by means of the interindustry model, using the endogenously determined input-output coefficients. The resulting energy flows therefore consistently incorporate energy and nonenergy price effects, input and consumption pattern adjustments and the interaction of the energy and nonenergy sectors of the economy.

The macro-econometric growth model consists of endogenous production and household sectors and exogenous foreign and government sectors. The model integrates demand and supply conditions for consumption, investment, capital and labor. Dynamic aspects of capital accumulation and consumer behavior are incorporated. The model determines components of gross national product and the relative prices of labor and capital services used in the interindustry model.

The model can be used to project U.S. economic growth and energy utilization. It can be used to study the impact of policy changes on energy prices and demands and on prices and economic growth in general. Specific applications of the model in the paper include a set of projections of energy use and its composition, an analysis of structural changes resulting from an energy use tax, and an estimate of the effects of an energy tax policy designed to promote energy independence.

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1. INTRODUCTION

The dramatic increase in world petroleum prices associated with the Arab oil embargo of October 1973 has highlighted the need for a new approach to the quantitative analysis of economic policy. Econometric models in the Tinbergen-Kelin mold have proved to be very useful in studying the impact of economic policy on aggregate demand.[1] At the same time these models do not provide an adequate basis for assessing the impact of economic policy on supply. Input-output analysis in the form originated by Leontief is useful for a very detailed analysis of supply, predicated on a fixed technology at any point of time.[2] Input-output analysis does not provide a means of assessing the impact of changes in technology induced by price variations associated with changes in economic policy.

The purpose of this paper is to present a new approach to the quantitative analysis of U.S. energy policy.[3] This approach is based on an integration of econometric modeling and input-output analysis and incorporates an entirely new methodology for assessing the impact of economic policy on supply. We combine the determinants of energy demand and supply within the same framework and relate patterns of U.S. economic growth to both demand and supply. Our approach can be used to project U.S. economic growth and energy utilization for any proposed U.S. energy policy. It can be employed to study the impact of specific policy changes on energy demand and supply, energy price and cost, energy imports and exports, and on U.S. economic growth.

The first component of our framework for energy policy analysis is an econometric model of interindustry transactions for nine domestic industries. We have sub-divided the business sector of the U.S. economy into nine industrial groups in order to provide for the detailed analysis of the impact of U. S. energy policy on the sectors most directly affected by policy changes. The nine sectors included in the model are:

1. Agriculture, non-fuel mining, and construction.
2. Manufacturing, excluding petroleum refining.
3. Transportation.
4. Communications, trade, and services.
5. Coal mining.
6. Crude petroleum and natural gas.
7. Petroleum refining.
8. Electric utilities.
9. Gas utilities.

Our inter-industry model includes a model of demand for inputs and supply of output for each of the nine industrial sectors. The model is closed by balance equations between demand and supply for the products of each of the nine sectors.

The principal innovation of our inter-industry model is that the input-output coefficients are treated as endogenous variables rather than exogenously given parameters. Our model for producer behavior determines the input-output coefficients for each of the nine sectors listed above as functions of the prices of products of all sectors, the prices of labor and capital services, and the prices of competing imports. We determine the prices of all nine products and the matrix of input-output coefficients simultaneously. In conventional input-output analysis the technology of each sector is taken as fixed at any point of time. Prices are determined as functions of the input-output coefficients, but the input-output coefficients themselves are treated as exogenously given parameters. Our approach integrates conventional input-output analysis with a determination of the structure of technology through models of supply for each industrial sector.

The second component of our framework for energy policy analysis is a macro-econometric growth model. The complete model consists of endogenous business and household sectors and exogenous foreign and government sectors. The chief novelty of our growth model is the integration of demand and supply conditions for consumption, investment, capital, and labor. The model is made dynamic by links between investment and changes in capital stock and between capital service prices and changes in investment goods prices. The model determines both components of gross national product in real terms, generated by conventional macro-econometric models, and relative prices of labor and capital services required by our econometric model of inter-industry transactions.

Our approach to the analysis of macro-economic activity can be contrasted with the analysis that underlies macro-econometric models used for short-term forecasting. Short-term forecasting is based on the projection of demand by foreign and government sectors and the determination of the responses of households and businesses in the form of demands for consumption and investment goods. The underlying economic theory is essentially the Keynesian multiplier, made dynamic by introducing lags in the responses of households and businesses to changes in income. In short-term macro-econometric models the supply side is frequently absent or present in only rudimentary form.[4] Our approach integrates the determinants of demand employed in conventional macro-econometric models with the determinants of supply; this integration is essential to the successful implementation of our inter-industry model.

Given a framework that incorporates the determinants of demand and supply for energy in the U.S. economy, our first objective is to provide a reference point for the analysis of energy policy by establishing detailed projections of demand and supply, price and cost, and imports and exports for each of the nine industrial sectors included in our model. For this purpose we project the level of activity in each industrial sector and relative prices for the products of all sectors for the years 1975-2000. Our projections include the level of macro-economic activity in the U.S. economy and the matrix of input-output coefficients for each year. Projections for the five industrial sectors that form the energy sector of the U.S. economy provide the basis for translating our detailed projections into the energy balance framework that has become conventional in the analysis of patterns of energy utilization.[5]

Our inter-industry approach imposes the same consistency requirements as the energy balance approach, namely, that demand is equal to supply in physical terms for each type of energy. In addition, our approach requires that demand and supply are consistent with the same structure of energy prices. This additional consistency requirement is absent from energy balance projections and requires the integration of energy balance projections with projections of energy prices. Our inter-industry model provides a means of combining these projections within a framework that also includes prices and inter-industry transactions for the sectors that consume but do not produce energy.

To illustrate the application of our model to the analysis of U.S. energy policy we have analyzed the effects of tax policies to stimulate energy conservation on the future pattern of energy utilization. Our methodology for policy analysis begins with a set of projec-

tions that assume no major new departures in energy policy. We then prepare an alternative set of projections incorporating the proposed change in policy. In analyzing the impact of tax policy we have incorporated the effect of energy taxes on demand and supply for energy. We find that price increases provide the economic incentive for the adoption of energy conservation measures that will result in considerable savings of energy. Tax policies or other measures to increase the price of energy could result in U.S. independence from energy imports by 1985.

We present our model for inter-industry transactions in Section 2 of the paper. In Section 3 we present econometric models of producer behavior for each of the nine sectors included in our inter-industry model. In Section 4 we present projections of economic activity and energy utilization for the period 1975-2000. In Section 5 we discuss a tax program for stimulating energy conservation and eliminating reliance of the U.S. economy on energy imports. (Because of space limitations the macro-econometric growth model is not presented in detail. A detailed description of the growth model can be found in Edward A. Hudson and Dale W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975-2000", forthcoming in The Bell Journal of Economics and Management Science, Autumn 1974.

2. INTER-INDUSTRY MODEL

2.1 Introduction. The first component of our framework for energy policy analysis is a model of inter-industry transactions for the United States. Rather than analyzing energy utilization in isolation, we begin with an analysis of the entire U.S. economy and then proceed to a detailed examination of the energy sector as one among many interdependent components of the economy. This perspective is necessarily more complex and more detailed than traditional perspectives on the anlysis of the energy sector, but is indispensible to the study of the interaction of energy resources and the growth of the U.S. economy.

Our inter-industry model permits the analysis of the entire chain of production from the purchase of primary inputs through the various intermediate stages of production to the emergence of final products to be absorbed in consumption, investment, government, or export final demand. The structure of production includes all of U.S. domestic supply of goods and services, but our specification provides for detailed analysis of the impact of U.S. energy policy on the sectors most directly affected by policy changes. We have classified production into nine industrial sectors, each of which purchases primary inputs, makes purchases from and sales to the other producing sectors, and sells finished output to final users. The flow of inter-industry transactions is represented in diagrammatic form in Table 1.

Our inter-industry model consists of balance equations between supply and demand for the products of each of the nine sectors included in the model. The model also includes accounting identities between the value of domestic availability of these products and the sum of values of intermediate input into each industry, value added in the industry, and imports of competing products. Demands for the products include demands for use as inputs by each of the nine sectors included in the model. The rest of domestic availability is allocated among four categories of final demand: personal consumption expenditures, gross private domestic investment, government expenditures, and exports.

In the model for projecting energy demand and supply we take the levels of final demand for all industries from the macro-econometric model presented in Section 4, below. Second, for the five energy sectors of the model we take the price and quantity of imports to be exogenous. For the four non-energy sectors we take the prices of imports as exogenous and determine import quantities along with the quantities of capital and labor services in each industry.[16] The prices of capital and labor services are determined within the macro-econometric model. We take the quantities of exports and government purchases of the output of each industry as exogenous. We also take the allocation of investment among the industries of origin to be exogenous.

Our inter-industry model consists of models of producer behavior for each of the nine industries included in the model. Producer behavior in each industry can be characterized by input-output coefficients for the input of products of each of the nine sectors, inputs of capital and labor services, and, for the four non-energy sectors, the level of competitive imports. An inter-industry approach to the study of energy resources is essential since most energy is consumed as an intermediate rather than a final product of the economy, Examples of intermediate products would be fossil fuels consumed by the electric generating sector. Examples of final products would be gasoline and heating oil consumed by the household and government sectors. Energy balance models provide projections of the levels of both intermediate and final demand.

Given the prices of domestic availability of the output of each sector included in our model, we determine the allocation of personal consumption expenditures among commodity groups distinguished in the model, using our model of consumer behavior. Person-

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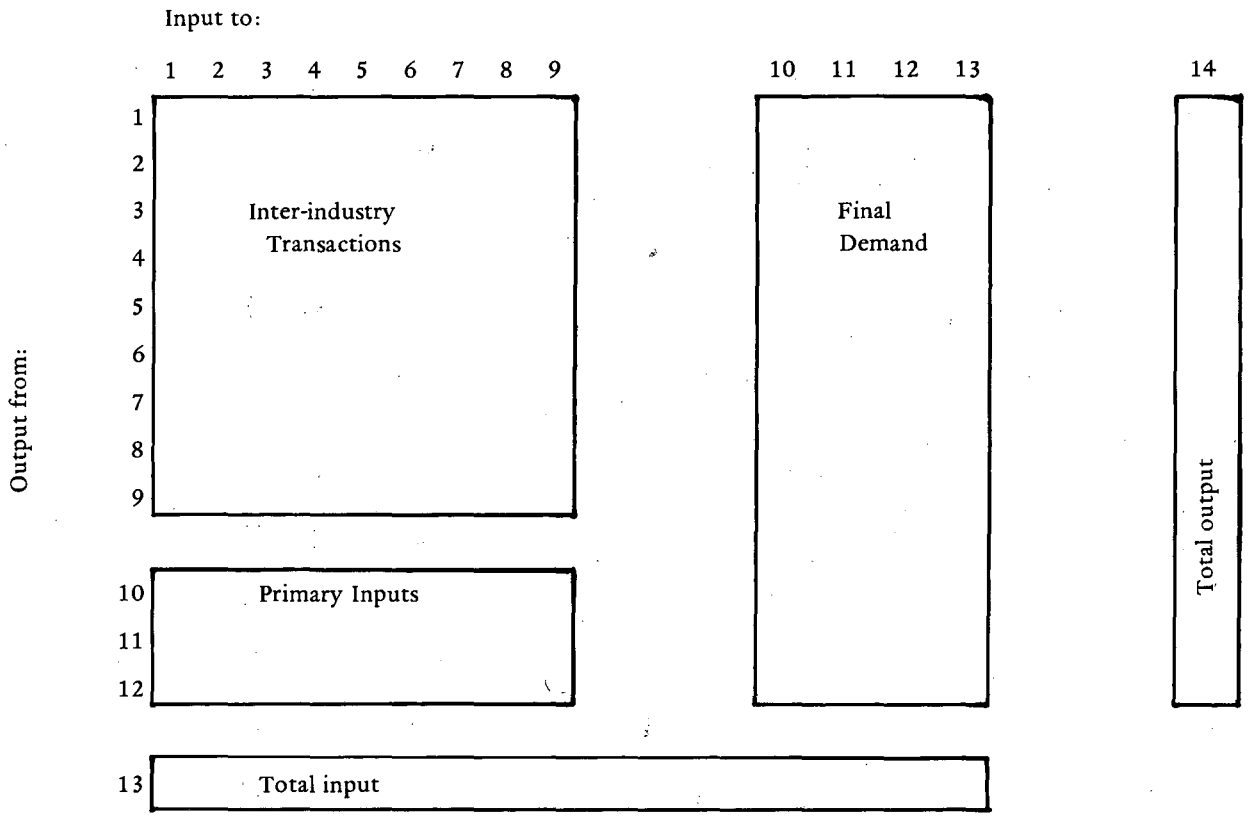
Table 1

Inter-industry Transactions: Diagrammatic Representation



Intermediate sectors:

1. Agriculture, non-fuel mining and construction.
2. Manufacturing, excluding petroleum refining.
3. Transport.
4. Communications, trade, services.
5. Coal mining.
6. Crude petroleum and natural gas.
7. Petroleum refining.
8. Electric utilities.
9. Gas utilities.

Primary inputs, rows:

10. Imports
11. Capital services.
12. Labor services.

Final demand, columns:

10. Personal consumption expenditures.
11. Gross domestic private investment.
12. Government purchases of goods and services.
13. Exports.

al consumption expenditures include deliveries to the household sector by eight of the nine sectors included in our inter-industry model of the producing sector. There are no direct deliveries of crude petroleum and natural gas to personal consumption expenditures. These products are delivered first to the petroleum refining and gas utility sectors and then to personal consumption expenditures and to other categories of intermediate and final demand.

Personal consumption expenditures also include non-competitive imports and the services of dwellings and consumers' durables. The levels of personal consumption expenditures on each of the eleven commodity groups included in our model of the household sector are determined from the projected level of personal consumption expenditures from the macro-econometric model, from the prices of domestic availability of the output of each sector included in the inter-industry model, and from the prices of non-competitive imports, consumers' durables services, and housing services. The price of non-competitive imports is taken to be exogenous. The capital service prices for consumers' durables services and housing services are determined from the price of capital services determined in the macro-econometric model.

The equations representing the balance of demand and supply for each of the nine sectors of the inter-industry model set domestic availability equal to the sum of intermediate demands and final demand. Intermediate demands are determined simultaneously with the levels of output of each industry, given input-output coefficients determined in the model of producer behavior. The input-output coefficients are determined simultaneously with the prices of domestic availability of the output of each industry. Finally, levels of capital and labor services for all sectors and competitive imports for the four non-energy sectors are determined from the levels of domestic availability and the corresponding input-output coefficients. These levels can be compared with the levels projected in the macro-econometric model.

2.2 Inter-Industry Transactions. We first describe our model of inter-industry transactions and then outline the application of this model to the projection of energy demand and supply; our notation is as follows:

XIJ = intermediate demand for the output of industry I by industry J_j

YI = final demand for the output of industry I;

XI = domestic availability of the output of industry I;

PI = price of the output of industry I.

To simplify the notation we take the price of the output of each industry to be the same in all uses. The deflators for each category of intermediate and final demand can differ. In projecting energy demand and supply we take the ratios of the deflator for the individual categories of demand to the deflator for domestic availability of output of the industry to be exogenous.

The inter-industry model consists of equality between demand and supply for each of the nine sectors included in the model. The balance equations for the nine sectors are:

$$XI = \sum_{J=1}^{9} XIJ + YI, \qquad (I=1,2...9) .$$

In addition, the model includes accounting identities between the value of domestic availability and the sum of values of intermediate input into the industry, value added in the industry, and, for the four-non-energy sectors, the imports of competing products:

$$PI*XI = \sum_{J=1}^{9} PJ*XJI + PK*KI + PL*LI + PRI*RI,$$

$$(I=1,2...9),$$

where:

KI = quantity of capital services in industry I;

LI = quantity of labor services in industry I;

RI = competitive imports of the output of industry I;

PK = price of capital services;

PL = price of labor services;

PRI = price of competitive imports of the output of industry I.

Again, prices of capital and labor services can differ among industries. To simplify notation we take the prices of these productive factors to be the same in all industries. In projecting energy demand and supply we take the ratios of service prices for each industry to the corresponding prices from the macro-econometric model to be exogenous.

Our inter-industry model includes models of producer behavior for each of the nine industrial sectors included in the model. These models of producer behavior can be derived from price possibility frontiers for the nine sectors:

$$AI*PI = GI(P1, P2,... P9; PK, PL, PRI),$$

$$(I = 1, 2...9) ,$$

where AI (I = 1, 2...9) is an index of Hicks-neutral technical change in industry I. The price possibility frontier for each sector can be derived from price possibility frontiers for each of the three sub-models employed in our analysis of production structure:[7]

1. a model giving the price of output as a function of prices of four aggregate inputs in each sector – capital (K), labor (L), energy (E), and materials (M);

2. a model giving the price of aggregate energy input in each sector as a function of the prices of the five types of energy included in the model – coal, crude petroleum and natural gas, refined petroleum products, electricity, and gas as a product of gas utilities;

3. a model giving the price of aggregate non-energy input in each sector as a function of the prices of the five types of non-energy input into each sector – agriculture, manufacturing, transportation, communications, and, for the four non-energy sectors, competitive imports.

Given the prices of capital services, labor services, and competitive imports in each of the four non-energy sectors, we can determine the prices of domestic availability of output PI (I = 1, 2... 9) for all nine sectors. To determine these prices we solve twenty-seven equations for prices of domestic availability, prices of aggregate energy input, and prices of aggregate non-energy input into all nine sectors. This system of twenty-seven equations consists of three equations for each sector. These three equations correspond to production possibility frontiers for each of the three sub-models for each sector. In these computations we are making use of a nonsubstitution theorem of the type first discussed by Samuelson.[8] This theorem states that for given prices of the factors of production and competitive imports, the prices of domestic availability of the output of each sector are independent of the composition of final demand.

The second step in our analysis of inter-industry transactions is to derive input-output coefficients for each of the nine industrial sectors included in our inter-industry model. The input-output coefficients can be expressed as functions of the prices. First, the relative share of the jth intermediate input can be determined from the identity:

$$\frac{\partial \ln PI}{\partial \ln PJ} = \frac{P_J{}^*X_JI}{PI^*XI} = \frac{P_J}{PI}{}^*AJI, \quad (I, J = 1,2...9),$$

where AJI is the input-output coefficient corresponding to XJI; it represents the input of the output of industry J per unit of output of industry I. Similar identities determine the relative shares of capital and labor services and competitive imports.[9]

Second, we can divide the relative shares by the ratio of the price of domestic availability of the output of the Jth industry PJ to the price for the Ith industry PI to obtain the input-output coefficients:

$$\frac{XJI}{XI} = AJI(P1, P2...P9; PK, PL, PRI),$$

$$(I, J = 1, 2...9);$$

and:

$$\frac{KI}{XI} = AKI = (P1, P2...P9; PK, PL, PRI),$$

$$\frac{LI}{XI} = ALI(P1, P2...P9; PK, PL, PRI),$$

$$\frac{RI}{XI} = ARI(P1, P2...P9; PK, PL, PRI),$$

$$(I,= 1, 2...9).$$

For each industry we derive the input-output coefficients in two steps: First, we determine the input-output coefficients for the aggregate inputs - - capital (K), Labor (L), energy (E), and materials (M). Second, we determine the input-output coefficients for the input of each type of energy input per unit of total energy input and the input of each type of non-energy input per unit of total non-energy input. To obtain the input-output coefficients required for our inter-industry model we multiply the input-output coefficients for each type of energy by the input-output coefficient for total energy. Similarly, we multiply the input-output coefficients for each type of non-energy input by the input-output coefficients for total non-energy input. We obtain input-output coefficients for capital services, labor services, five types of energy inputs into each sector and five types of non-energy inputs into each sector.

The input-output coefficients for each of the nine industrial sectors included in our model of inter-industry transactions are functions of the prices of capital services, labor services, and competitive imports for the four non-energy sectors and the prices of domestic availability of the output of each of the nine sectors. The prices of domestic availability are functions of the prices of capital services, labor services, and competitive imports for the four non-energy sectors. By the nonsubstitution theorem both prices of domestic availability and input-output coefficients are independent of the composition of final demand.[10]

2.3 Final demand. Final demand for domestic availability of the output of each of the nine sectors included in our inter-industry model is allocated among personal consumption expenditures, gross private domestic investment, government expenditures, and exports. In projecting energy demand and

supply we take aggregate levels of each category of final demand from our macro-economic projections. We allocate personal consumption expenditures among the nine sectors included in our model, employing aggregate personal consumption expenditures as total expenditures, on the basis of the prices of domestic availability of the output of all nine sectors. Government expenditures and exports of the output of each sector are exogeneous. Imports of the output of the five energy sectors are also exogenous so that we include only exports net of imports in final demand for these sectors. We take aggregate private domestic investment from our macro-economic projections. We take the relative proportion of investment in the output of each industrial sector included in our inter-industry model to be exogenous.

The final step in determining the level and composition of inter-industry transactions is to determine the levels of output, employment, and utilization of capital for each of the nine industrial sectors included in our model and competitive imports for the four non-energy sectors included in the model. This part of our model coincides with conventional input-output analysis. Given the input-output coefficients for all nine sectors, we can determine the level of output for each sector for any given levels of final demand for the output of all nine sectors. We present projected matrices of inter-industry transactions in energy for the years 1975, 1985 and 2000 in Section 5 below. We also present projections of energy prices for each year.

Final demand for domestic availability of the output of each of the nine sectors included in the model is allocated among consumption, investment, government expenditures, and exports:

$$YI = CI + II + GI + ZI, \ (I = 1, 2...9),$$

where:

- CI = personal consumption expenditures on the output of industry I;
- II = gross private domestic investment in the output of industry I (the sum of gross private fixed investment and net inventory change);
- GI = government expenditure on the output of industry I;
- ZI = exports of the output of industry I (exports less imports for the five energy sectors).

We project gross domestic investment in current and constant prices in our macro-econometric model. To project energy demand and supply we allocate gross private domestic investment among the nine industry groups included in the model. The relative proportions of investment originating in each sector is taken to be exogenous. In a completely dynamic model the allocation of investment by sector of origin and sector of destination would be endogenous. Our macro-econometric model incorporates the dynamics of saving and investment only in the projection of total investment. The allocation of capital by sector of destination is endogenously determined, but the allocation of investment by sector of origin in exogenous.

The personal consumption expenditure component of final demand is generated by an econometric model of consumer behavior. This model allocates consumption expenditure over the products of the nine intermediate sectors and non-competitive imports and the services of consumers' durables. The model is based on an indirect utility function that can be represented:[11]

$$\ln V = \ln V\left(\frac{P1}{PC^*C}, \frac{P2}{PC^*C}, \ldots, \frac{P11}{PC^*C}\right)$$

where V is the level of utility, PI is the price of the Ith commodity and PC*C is total personal consumption expenditures. The present consumption model uses a linear logarithmic indirect utility function. This corresponds to fixed budget shares. The total value of personal consumption expenditures is determined in the macro-econometric model. The price of domestic availability of the output of each sector is determined in our models of producer behavior. Therefore, given total expenditure and prices, we can find the quantities demanded of each commodity for personal consumption expenditures.

Real final demand for the output of each of the nine industrial sectors is the sum of final demand for personal consumption, gross private domestic investment, govenment purchases and exports. The vector Y of real final demand is then inserted into demand-supply balance equations for nine sectors of our inter-industry system:

$$XI = \sum_{J=1}^{9} XIJ^*J + YI$$

$$= \sum_{J=1}^{9} AIJ^*XJ + CI + II + GI + ZI, (I=1,2...9),$$

where the input-output coefficients $\{AIJ\}$ have already been determined endogenously together with the output prices $\{PI\}$.

The levels of domestic availability of each sector, {XI}, are obtained by solving the input-output equation system:

$$XI = \sum_{J=1}^{9} AIJ*XJ + YI \quad (I = 1, 2...9).$$

Levels of capital and labor services and competitive imports for the nonenergy sectors are determined from the levels of domestic availability and the corresponding input-output coefficients:

$$KI = AKI*XI, \; LI = ALI*XI, \; RI = ARI*XI,$$

$$(I = 1, 2...9).$$

Table 2 presents a flow chart for the structure, and solution path, of our complete econometric model.

3. PRODUCER BEHAVIOR

3.1. Introduction. Our inter-industry model includes econometric models of producer behavior for each of the nine industrial sectors included in the model.[12] In implementing an econometric model of producer behavior for each sector our primary objective is to explore the inter-relationships between relative demand for energy and relative demand for capital services, labor services, and non-energy inputs. Similarly, we wish to explore the inter-relationships among relative demands for the five types of energy included in our model - - coal, crude petroleum and natural gas, refined petroleum products, electricity and gas as a product of gas utilities. We have imposed a structure on the price possibility frontier that permits us to deal with relative demand for energy as a whole and relative demands for the five types of energy included in our model as two separate problems. This production structure is defined in terms of the following groups of inputs:

1. Capital (K).
2. Labor (L).
3. Energy (E). This group consists of inputs of coal, crude petroleum and natural gas, refined petroleum products, electricity, and gas as a product of gas utilities.
4. Materials (M). This group consists of inputs of agriculture, manufacturing, transportation, communications, trade and services, and competitive imports for the non-energy sectors.

We first construct a model for producer behavior in terms of the four aggregates - capital, labor, energy, and materials. We represent the price of domestic availability of the output of each sector as a function of the prices of each of the aggregates. A sufficient condition for the price possibility frontier to be defined on the prices of the four aggregates is that the overall price possibility frontier is separable and homogeneous in the inputs within each aggregate.[13] The price possibility frontier is separable in the commodities within an aggregate if and only if the ratio of the relative shares of any two commodities within an aggregate is independent of the prices of commodities outside the aggregate.[14] For example, the five types of energy make up an appropriate aggregate if the relative value shares of any two types of energy depend only on the prices of energy and not on the prices of non-energy intermediate inputs or the prices of capital and labor services.

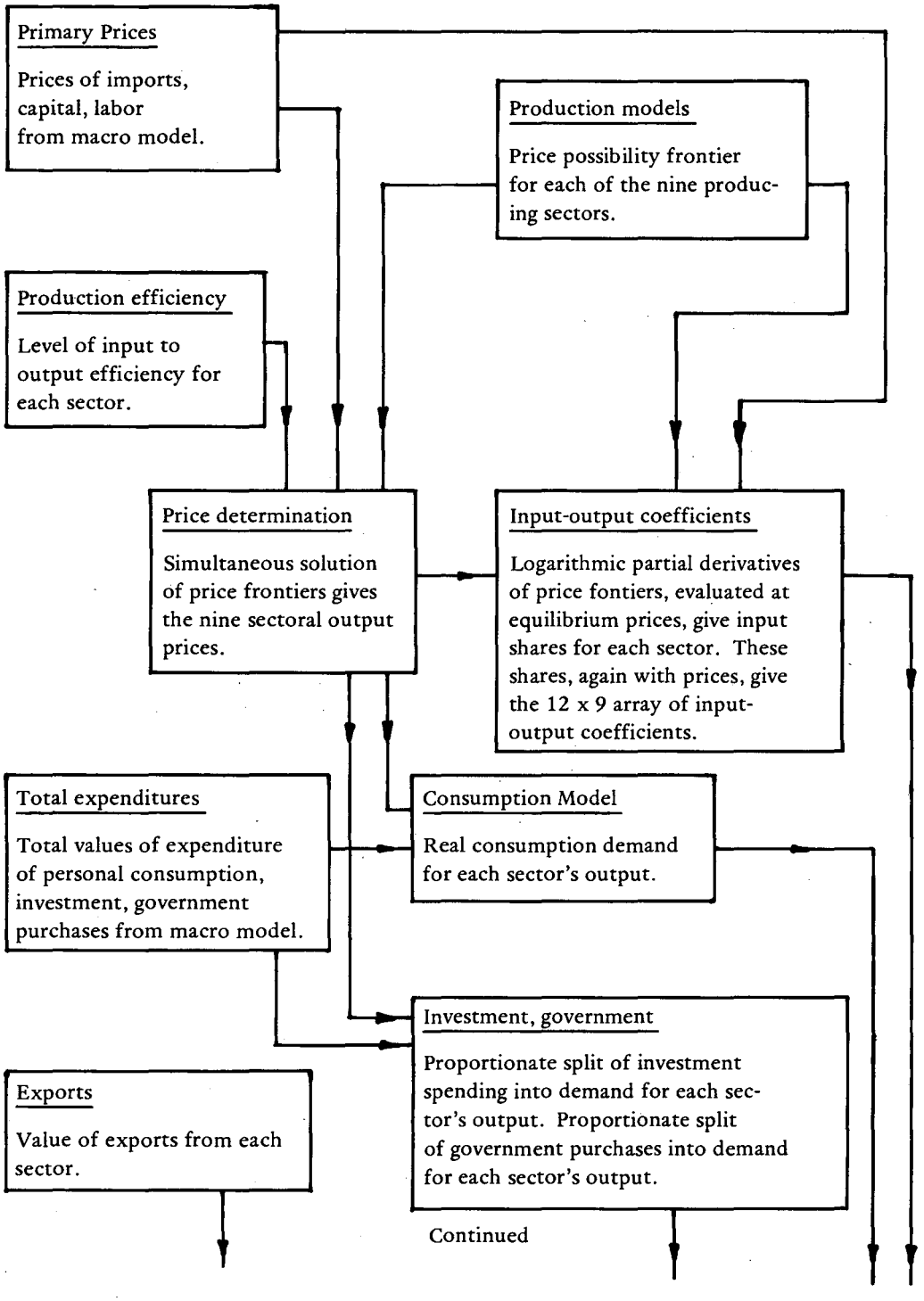
The second step in constructing a model of producer behavior is to represent the price possibility frontier for the energy and materials aggregates as functions of the prices of inputs that make up each of the aggregates. For the energy aggregate the price of energy is represented as a function of the prices of the five types of energy that make up the aggregate - - coal, crude petroleum and natural gas, refined petroleum products, electricity, and gas as a product of gas utilities. For the materials aggregate the price of materials is represented as a function of the five types of inputs that make up the aggregate - - agriculture, manufacturing, transportation, communications, trade, and services, and competitive imports for the non-energy sectors.

3.2. Econometric specification. The system of relative demand functions employed in our econometric model of producer behavior for each of the nine industrial sectors of our model is generated from the price possibility frontier for the corresponding sector. For each of the three sub-models that make up our model of producer behavior we represent the price possibility frontier by a function that is quadratic in the logarithms of the prices of the inputs into the sector. The resulting price possibility frontier provides a local second-order approximation to any price possibility frontier. We refer to our representation as the transcendental logrithmic price possibility frontier or, more simply, the translog price possibility frontier. The price possibility frontier is a transcendental function of the logrithms of the prices of inputs. The translog price possibility frontier was introduced by Christensen, Jorgenson, and Lau.[15]

As an example, the price possibility frontier for the aggregate (KLEM) sub-model takes the form:

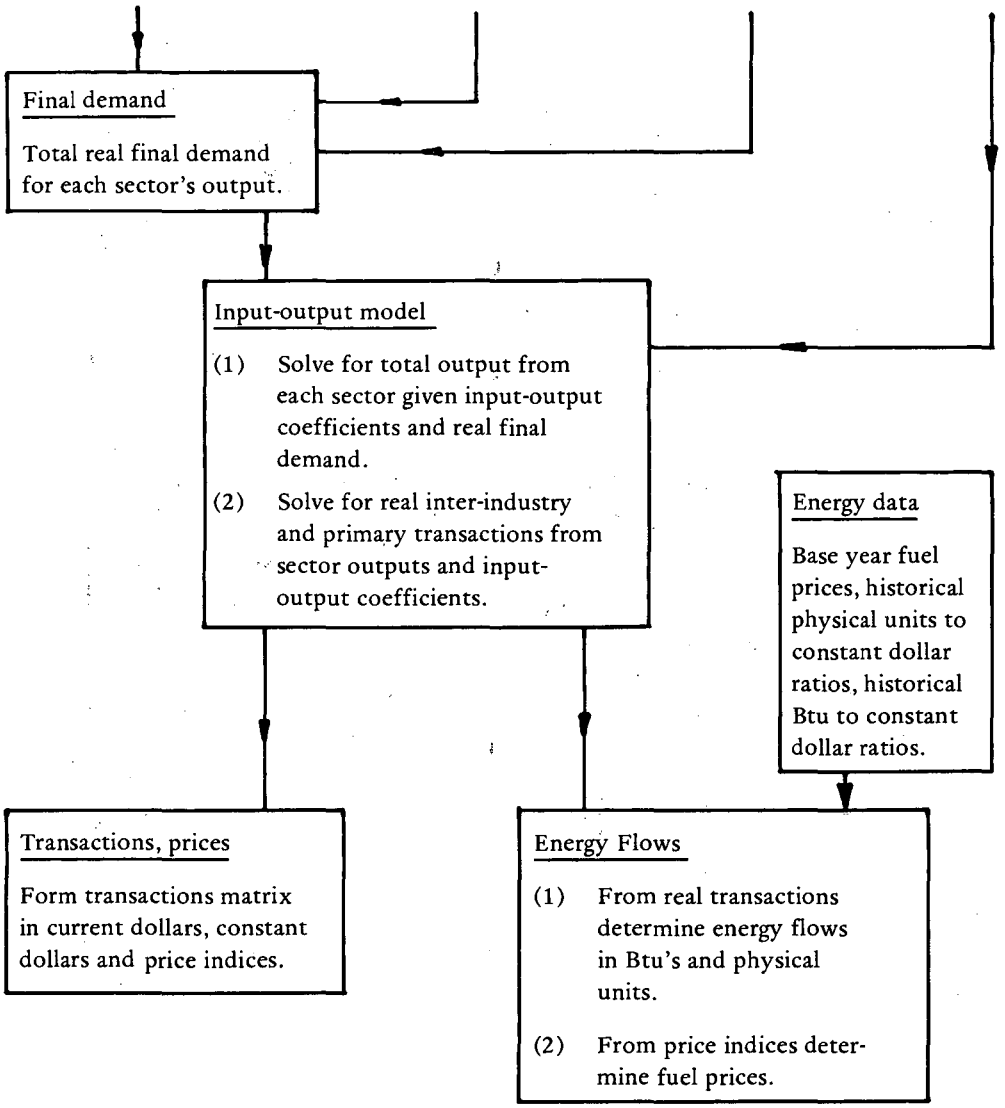
Table 2

Inter-industry Econometric Model: Diagrammatic Representation



Continued

Table 2 (concluded)



$$\ln AI + \ln PI = \alpha^I_0 + \alpha^I_K \ln PK + \alpha^I_L \ln PL + \alpha^I_E \ln PE + \alpha^I_M \ln PM + \frac{1}{2}[\beta^I_{KK} (\ln PK)^2 + \beta^I_{KL} \ln PK \ln PL + \ldots],$$

where PK is the price of capital services, PL the price of labor services, PE the price of energy, and PM the price of materials. For this form of the price possibility frontier, the equations for the relative shares of the four input aggregates take the form:

$$\frac{PK*KI}{PI*XI} = \alpha^I_K + \beta^I_{KK} \ln PK + \beta^I_{KL} \ln PL + \beta^I_{KE} \ln PE + \beta^I_{KM} \ln PM,$$

$$\frac{PL*LI}{PI*XI} = \alpha^I_L + \beta^I_{LK} \ln PK + \beta^I_{LL} \ln PL + \beta^I_{LE} \ln PE + \beta^I_{LM} \ln PM,$$

$$\frac{PE*EI}{PI*XI} = \alpha^I_E + \beta^I_{EK} \ln PK + \beta^I_{EL} \ln PL + \beta^I_{EE} \ln PE + \beta^I_{EM} \ln PM ,$$

$$\frac{PM*MI}{PI*XI} = \alpha^I_M + \beta^I_{MK} \ln PK + \beta^I_{ML} \ln PL + \beta^I_{ME} \ln PE + \beta^I_{MM} \ln PM ,$$

$$(I=1,2...9),$$

where KI is the quantity of capital services in the Ith sector, LI the quantity of labor services, EI the quantity of energy input, and MI the quantity of materials input.[16]

The dependent variable in each of the four functions generated from the translog price possibility frontier is the relative share of the corresponding input. To derive the input-output coefficient for that input, we divide the relative share by the ratio fo the price of the input to the price of the output of the sector. For example, the input-output coefficients for capital services are:

$$AKI = \frac{KI}{XI} ,$$

$$= (\alpha^I_K + \beta^I_{KK} \ln PK + \beta^I_{KL} \ln PL + \beta^I_{KE} \ln PE + \beta^I_{KM} \ln PM)/(PK/PI),$$

$$(I = 1, 2...9).$$

Similar expressions can be obtained for the input-output coefficients for labor services, energy, and materials.

The value of domestic availability of the output of each sector is equal to the sum of the values of capital and labor services in that sector and the value of energy and non-energy inputs into the sector:

$$PI*XI = PK*KI + PL*LI + PE*EI + PM*MI ,$$

$$(I = 1, 2...9).$$

Given this accounting identify, the relative shares of the four aggregate inputs into each sector add to unity. The parameters of the four relative demand functions for capital and labor services and energy and non-energy inputs must satisfy the restrictions:

$$\alpha^I_K + \alpha^I_L + \alpha^I_E + \alpha^I_M = 1 ,$$

$$\beta^I_{KJ} + \beta^I_{LJ} + \beta^I_{EJ} + \beta^I_{MJ} = 0 \quad (I=1,2...9); J=K,L,E,M).$$

Given estimates of the parameters of any three equations for the relative shares, estimates of the parameters of the fourth equation can be determined from these restrictions.

The logarithm of the price possibility frontier for each sector is twice differentiable in the logarithms of the prices of inputs, so that the Hessian fo this function is symmetric. This gives rise to a set of restrictions relating the parameters of cross partial derivatives. For the aggregate (KLEM) sub-model three of these restrictions are explicit in the three equations we estimate directly, namely:

$$\beta^I_{KL} = \beta^I_{LK}, \beta^I_{KE} = \beta^I_{EK}, \beta^I_{LE} = \beta^I_{EL} \quad (I = 1, 2...9).$$

In addition, we estimate the parameters β^I_{MK}, β^I_{ML}, and β^I_{ME} (I = 1,... 9) from the equations:

$$\beta^I_{MK} = -\beta^I_{KK} - \beta^I_{LK} - \beta^I_{EK} ,$$

$$\beta^I_{ML} = -\beta^I_{KL} - \beta^I_{LL} - \beta^I_{EL} ,$$

$$\beta^I_{ME} = -\beta^I_{KE} - \beta^I_{LE} - \beta^I_{EE} , \quad (I = 1, 2 ... 9) ,$$

so that three additional symmetry restrictions are implicit in the equations we estimate, namely:

$$\beta^I_{KM} = \beta^I_{MK}, \beta^I_{LM} = \beta^I_{ML}, \beta^I_{EM} = \beta^I_{ME} \quad (I=1,2...9).$$

For each of the nine industrial sectors, the aggregate (KLEM) sub-model involves six symmetry restrictions.

The price possibility frontier for each sector is homogeneous of degree one. This homogenity is implied by the symmetry conditions and by the restrictions imposed by the identity between input and output values. These restrictions, in total, reduce the twenty unknown parameters of the aggregate frontiers to nine parameters to be estimated.

We have presented the aggregate (KLEM) sub-model of our model of producer behavior in detail. The forms of the energy (E) and materials (M) sub-models are analogous to the form of the aggregate sub-model. For the energy sub-model we can write the translog price possibility frontier in the form:

$$\ell n\ PE = \alpha_0^{EI} + \alpha_1^{EI}\ 1n\ PE1 + \alpha_2^{EI}\ 1n\ PE2 + \alpha_3^{EI}\ 1n\ PE3 + \alpha_4^{EI}\ 1n\ PE4 + \alpha_5^{EI}\ 1n\ PE5 + \frac{1}{2}\ [\beta_{11}^{EI}\ (1n\ PE1)^2 + \beta_{12}^{EI}\ 1n\ PE1\ 1n\ PE2 + \ldots],$$

$$(I = 1,2 \ldots 9),$$

where PE1 is the price of coal, PE2 the price of crude petroleum and natural gas, PE3 the price of refined petroleum products, PE4 the price of electricity, and PE5 the price of gas as a product of gas utilities. Similarly, we can write the translog price possibility frontier for the materials sub-model in the form:

$$\ell n\ PM = \alpha_0^{MI} + \alpha_1^{MI}\ 1n\ PM1 + \alpha_2^{MI}\ 1n\ PM2 + \alpha_3^{MI}\ 1n\ PM3 + \alpha_4^{MI}\ 1n\ PM4 + \alpha_5^{MI}\ 1n\ PM5 + \frac{1}{2}\ [\beta_{11}^{EI}\ (1n\ PM1)^2 + \beta_{12}^{EI}\ 1n\ PM1\ 1n\ PM2 + \ldots].$$

$$(I = 1,2 \ldots 9),$$

where PM1 is the price of agriculture, non-fuel mining, and construction, PM2 the price of manufacturing, excluding petroleum refining, PM3 the price of transportation, PM4 the price of communications, trade and services, and PM5 the price of competitive imports.

For both energy (E) and materials (M) sub-models we can derive a system of five equations for determining the relative shares of the five commodity groups making up each sub-model. Each equation gives the relative share of one of the commodity groups as a function of the prices of all five groups included in the sub-model. We can derive the relative demand functions for each commodity group by dividing the relative value share of the group by the ratio of the price of that group to the price of the corresponding aggregate. For example, to derive the demand for coal relative to total energy we divide the relative value share of coal by the ratio of the price of coal to the price of total energy. We can derive the input-output coefficient for coal by multiplying the demand for coal relative to total energy by the demand for energy relative to the output of the corresponding industrial sector.

The value of each aggregate is equal to the sum of the values of the commodity groups that make up that aggregate. For example, the value of energy is equal to the sum of the values of each of the five types of energy:

$$PE*EI + PE1*E1I + PE2*E2I + PE3*E3I + PE4*E4I + PE5*E5I,$$

$$(I = 1,2 \ldots 9),$$

where E1I is the quantity of coal, E2I the quantity of crude petroleum and natural gas, E3I the quantity of refined petroleum products, E4I the quantity of electricity, and E5I the quantity of gas as a product of gas utilities. As before, the relative shares of the five energy inputs add to unity, so that the parameters of the five relative demand functions for these inputs must satisfy restrictions analogous to the restrictions given above for the parameters of the aggregate (KLEM) sub-model. Similar restrictions hold for the five relative demand functions for non-energy inputs.

3.3. Parameter estimation. For each of the nine intermediate production sectors the aggregate (KLEM) sub-model consists of four equations. We fit the three equations for relative shares of capital (K), labor (L), and energy (E). The materials (M) parameters can then be determined from the symmetry restrictions and the accounting identity between the value of input and value of output. (Also, taking convexity restrictions into account where appropriate permits a further reduction in the number of unknown parameters.)[17]

The energy (E) sub-model for each industrial sector consists of five equations for the relative shares of coal, crude petroleum and natural gas, refined petroleum products, electricity, and gas as a product of gas utilities. Four sectors - agriculture, manufacturing, services and petroleum refining - purchase each of the five energy inputs. In these cases four share equations are fitted with the remaining share, of gas as a product of gas utilities, being found from the four equations and the accounting identity between the total value of energy input and the sum of the values of the five types of energy. In the estimation of these shares the thirty initial unknown parameters in the energy sub-model are reduced, by symmetry conditions and by the value of energy accounting identity, to fourteen parameters to be estimated. In the remaining intermediate sectors zero restrictions permit a further reduction in the number of parameters to be estimated. In transportation, coal mining and electric utilities the share of crude petroleum and natural gas is zero, for gas utilities the share of electricity is zero. These restrictions permit only three share equations to be fitted for each sector with the fourth being determined from the value of energy accounting identity. (The symmetry restrictions then reduce the number of unknown parameters to nine.)

The crude petroleum and natural gas sector makes no purchases of coal or from gas utilities so only two share equations need be fitted. These restrictions, with the value identity and symmetry restrictions, reduce the number of unknown parameters in this sector's energy sub-model to five.

The materials (M) sub-model is similar to the energy sub-models. For the non-energy sectors four share equations are fitted - for inputs of agriculture, manufacturing, transportation and services - with the fifth share - that of competitive imports - being found from the accounting identity between the value of materials and the sum of the five types of materials inputs. Each of these sub-models involves fourteen unknown parameters. For the five energy sectors imports are exogenous so three share equations, involving nine unknown parameters, are fitted for each sector.

The three sub-models - aggregate (KLEM), energy (E), and materials (M) - for each of the nine sectors have been fitted to annual data on inter-industry transactions, capital services, labor services and competitive imports for the period 1947-71.[18] Estimation was by the minimum distance estimator for non-linear simultaneous equations, treating the prices of competitive imports as exogenous.[19] For each sub-model the equation system is non-linear in the variables but linear in the parameters.

Tables 3-5 present the estimates of the parameters of the translog price possibility frontier for each of the three sub-models of producer behavior for all nine intermediate sectors. The nine sectors are numbered as in Table 1. The energy and input subscripts refer to these sectors in the order that they appear in Table 1, and similarly for the material input subscripts.

4. ENERGY PROJECTIONS.

4.1. Introduction. Our next objective is to provide a reference point for the analysis of energy policy by establishing detailed projections of energy demand and supply, energy price and cost, and energy imports and exports. Our projections cover the years 1975, 1980, 1985 and 2000 and are based on the assumption that there are no major changes in energy policy, either by U. S. or foreign governments, over the forecast period. The projections include the entire matrix of inter-industry transactions in current dollar and in constant dollar flow. We translate this information into physical terms by converting the constant dollar energy transactions into British Thermal Units (Btu) for each fuel.[24] We also convert the price indexes into dollars

Table 3. Estimates of the parameters of the translog price possibility frontier for the aggregate (KLEM) sub-model for nine industrial sectors of the U.S. economy, 1947-71.

Parameter	Sectors 1	2	3	4	5	6	7	8	9
α_K^I	.1785	.1149	.1799	.2994	.1277	.4272	.1373	.3458	.2165
α_L^I	.2354	.2940	.4096	.4171	.4139	.0987	.0978	.1925	.1085
α_E^I	.0244	.0202	.0380	.0182	.1857	.1101	.4553	.2120	.5547
α_M^I	.5616	.5708	.3726	.2653	.2727	.3640	.3096	.2496	.1204
β_{KK}^I	.0851	.0590	.1018	.0595	.0280	.2447	.0849	.1330	.0749
β_{KL}^I	-.0366	-.0030	-.0601	.0114	-.0357	-.0422	-.0242	.0288	-.1181
β_{KE}^I	-.0052	-.0055	-.0137	.0011	.0099	-.0470	-.0772	-.1682	-.0941
β_{KM}^I	-.0434	-.0565	-.0280	-.0719	-.0022	-.1555	.0165	.0064	.1373
β_{LL}^I	.0287	.0737	.0582	.0848	-.0751	-.0131	-.0174	-.0968	-.2773
β_{LE}^I	.0023	.0054	-.0180	.0098	.1145	.0459	-.0122	.0239	.1318
β_{LM}^I	.0056	-.0821	.0199	-.1059	-.0037	.0093	.0538	.0441	.2636
β_{EE}^I	.0072	.0188	.0198	.0020	.0087	.0184	.2282	.0638	.1413
β_{EM}^I	-.0044	-.0187	.0119	-.0129	-.1332	-.0173	-.1388	.0805	-.1790
β_{MM}^I	.0422	.1573	-.0038	.1907	.1392	.1635	.0685	-.1311	-.2219

Table 4. Estimates of the parameters of the translog price possibility frontier for the energy (E) sub-model for nine industrial sectors of the U.S., 1947-71.

Parameter	Sectors 1	2	3	4	5	6	7	8	9
α_1^{EI}	.0053	.2040	.0799	.1142	.8510	.0738	.0448	.3165	.0909
α_2^{EI}	.0021	.0002	.0000	.0111	.0000	.1464	.2131	.0000	.1408
α_3^{EI}	.8389	.3384	.8107	.3520	.3997	.0894	.2289	.1173	.0940
α_4^{EI}	.1212	.2858	.0406	.4136	.1062	.6904	.5132	.3829	.6743
α_5^{EI}	.0325	.1716	.0688	.1091	.0029	.0000	.0000	.1829	.0000
β_{11}^{EI}	.0052	.1624	.0735	.1011	-.0118	-.0557	-.0165	.0762	-.0752
β_{12}^{EI}	.0000	.0000	.0000	-.0013	.0000	.1098	.0483	.0000	.1850
β_{13}^{EI}	-.0068	-.0690	-.0648	-.0402	.0220	-.0255	.0005	.0833	-.0192
β_{14}^{EI}	.0011	-.0583	-.0032	-.0472	-.0100	-.0286	-.0323	-.0578	-.0906
β_{15}^{EI}	.0005	-.0350	-.0055	-.0125	-.0002	.0000	.0000	-.1017	.0000
β_{22}^{EI}	.0010	-.0029	.0000	.0110	.0000	.0077	.1113	.0000	-.1416
β_{23}^{EI}	.0007	-.0001	.0000	-.0039	.0000	.0053	-.0592	.0000	.0455
β_{24}^{EI}	-.0007	.0073	.0000	-.0046	.0000	-.1228	-.1003	.0000	-.0889
β_{25}^{EI}	-.0010	-.0043	.0000	-.0012	.0000	.0000	.0000	.0000	.0000
β_{33}^{EI}	-.0252	.2239	.1534	.2281	-.0287	-.0418	.0680	.0001	-.0553
β_{34}^{EI}	.0128	-.0967	-.0329	-.1456	.0064	.0620	-.0092	-.0966	.0289
β_{35}^{EI}	.1854	-.0581	-.0557	-.0384	.0003	.0000	.0000	.0162	.0000
β_{44}^{EI}	-.0410	.1868	.0389	.2425	.0055	.0894	.1418	.2077	.1505
β_{45}^{EI}	.0278	-.0390	-.0028	-.0451	-.0019	.0000	.0000	-.0502	.0000
β_{55}^{EI}	-.0458	.1364	.0640	.0972	.0018	.0000	.0000	.1357	.0000

Table 5. Estimates of the parameters of the translog price possibility frontier for the materials (M) sub-model for nine industrial sectors of the U.S., 1947-71.

Parameter	Sectors 1	2	3	4	5	6	7	8	9
α_1^{MI}	.2578	.1348	.1221	.0819	.0193	.0779	.0562	.1134	.1759
α_2^{MI}	.3777	.5933	.1373	.2548	.4270	.0869	.1656	.1046	.1546
α_3^{MI}	.0653	.0472	.1932	.0532	.0675	.0501	.1736	.1200	.1453
α_4^{MI}	.2674	.1643	.4382	.5774	.4839	.5517	.4659	.6620	.4426
α_5^{MI}	.0318	.0603	.1091	.0327	.0023	.2334	.1388	.0000	.0815
β_{11}^{MI}	.0799	.0376	.1072	-.0454	.0190	.0718	.0530	.0170	-.0407
β_{12}^{MI}	-.1012	-.0200	-.0168	.0848	-.0083	-.0068	-.0093	.0755	.0845
β_{13}^{MI}	.0629	.0043	-.2360	-.0094	-.0013	-.0039	-.0097	-.0292	-.0703
β_{14}^{MI}	-.0672	-.0571	-.0535	-.0806	-.0094	-.0430	-.0262	-.0633	-.0899
β_{15}^{MI}	.0256	.0352	-.0133	.0506	-.0000	-.0182	-.0078	.0000	.1164
β_{22}^{MI}	.2349	.1958	.1185	.0973	-.2447	.0794	.1382	.0023	-.0070
β_{23}^{MI}	-.0219	-.0361	-.0265	-.0091	-.0288	-.0044	-.0288	.0037	-.0123
β_{24}^{MI}	-.1009	-.0710	-.0602	-.1179	-.2066	-.0480	-.0772	-.0815	-.0895
β_{25}^{MI}	-.0109	-.0687	-.0150	-.0550	-.0010	-.0203	-.0230	.0000	.0243
β_{33}^{MI}	.0039	.0435	.1559	.0502	.0629	.0476	.1434	.1027	.1095
β_{34}^{MI}	-.0187	-.0030	-.0847	-.0321	-.0327	-.0276	-.0809	-.0773	-.0739
β_{35}^{MI}	-.0263	-.0087	-.0211	.0005	-.0002	-.0117	-.0241	.0000	.0471
β_{44}^{MI}	.1959	.1218	.2462	.2348	.2497	.2473	.2488	.2221	.2346
β_{45}^{MI}	-.0090	.0093	-.0478	-.0042	-.0011	-.1287	-.0646	.0000	.0187
β_{55}^{MI}	.0206	.0329	.0972	.0081	.0023	.1789	.1195	.0000	-.2065

per physical unit. This transformation permits the expression of our detailed inter-dustry projections into the energy balance framework that is conventional in energy analysis.[25]

A summary of the composition and growth of the inter-industry transactions ofr the U. S. economy is given in Table 6. This table presents information on the gross output of each producing sector, together with information on the disposition side of GNP. The rate of growth of real GNP is expected to slow somewhat from recent levels, in large part because of the expected decline in the rate of increase of the labor force, but only to around 3.85% a year. Inflation also is expected to slow from rates experienced in the recent past but, at 3.76% a year, to remain above typical historical rates.

The composition of GNP is expected to change gradually. Net exports absorb an increasing fraction of GNP as the terms of trade, particularly relating to raw materials, continue to move against the U. S. Real government purchases fall in relation to total output although the rapid rate of increase in the price of

Table 6. U.S. Industry Output and Prices, 1975-2000 (Average annual growth rates, percent).

Output of Sector	Real Dollars	Prices	Current Dollars
1.	2.82	4.97	7.93
2.	3.92	3.49	7.55
3.	4.30	2.33	6.73
4.	3.51	4.15	7.81
5.	2.73	6.45	9.36
6.	1.64	4.46	6.17
7.	2.14	5.80	8.06
8.	5.16	2.99	8.30
9.	1.10	6.68	7.85
Consumption	3.82	3.64	7.60
Investment	3.80	3.93	7.88
Government	3.78	4.11	8.05
Net Exports	6.29	-	-
GNP	3.85	3.76	7.75

government purchases, primarily of its purchases of labor and services, offsets this and results in a small increase in the current dollar share of government purchases of GNP. Personal consumption in real terms increases in line with GNP but, because of the slower than average increase in consumption prices, the current dollar share of consumption in GNP falls. Private investment in real terms increases more slowly than GNP but, in current dollars, it increases more rapidly.

The composition of production changes more noticeably. Agriculture, non-fuel mining and construction output increases relatively slowly, as its output is income inelastic, while the expected productivity advance in manufacturing and transport permits a comparatively rapid increase in output from these sectors with less than average increase in prices. Communications, trade and services output continues to increase but less rapidly than real GNP and, due to the slow productivity advance in this sector and its relative intensity in an increasing cost input, labor, its prices increase comparatively rapidly.

4.2. Energy balance. Our projection of total U. S. energy utilization for the period 1975-2000 is summarized in Table 7. Total energy input is forecast to increase from 77.186 quadrillion Btu in 1975 to 161.241 quadrillion Btu in 2000, an average annual growth rate of 3.0%. The rate of increase of this total varies over time. In the past the rate of increase of total input has varied from 3.7% a year over the 1960-65 period. to 4.8% over 1965-70, to3.9% for 1970-73. Our forecast 1975 total corresponds to a 2.7% increase for the 1970-75 period.

The continued increase in fuel prices and the continued presence of some general interest in energy conservation, together with the changing structure of the economy, prevent the rate of increase in energy

Table 7. U.S. Energy Input, 1970-2000.

	1970	1975	1980	1985	2000
1. U.S. Total Energy Input (Quadrillion Btu)					
Coal	12.922	13.262	14.304	16.538	26.891
Petroleum	29.614	33.902	39.176	44.547	58.148
Natural gas (exc. syn. gas)	22.029	24.506	26.888	28.145	28.681
Hydro, nuclear, other	2.879	5.516	10.115	16.096	47.521
Total	67.444	77.186	90.484	105.326	161.241
2. Total Energy Input, Growth Rates (Average percent per annum)					
Coal		0.52	1.52	2.94	3.29
Petroleum		2.74	2.93	2.60	1.79
Natural gas		2.15	1.87	0.92	0.13
Hydro, nuclear, other		13.89	12.89	9.74	7.48
Total		2.74	3.23	3.08	2.88
3. Total Energy Input, Composition (Percent of total)					
Coal	19.16	17.18	15.81	15.70	16.68
Petroleum	43.91	43.92	43.30	42.29	36.06
Natural gas	32.66	31.75	29.72	26.72	17.79
Hydro, nuclear, other	4.27	7.15	11.18	15.28	29.47
Total	100.00	100.00	100.00	100.00	100.00

use from returning to historical trends. These forces lead to several avenues of energy conservation. Wasteful energy use is reduced, existing capital is gradually replaced with more energy efficient capital, and output shifts towards less energy-intensive forms, leading to a steady decline in the projected rate of increase of total energy input. Thus, projected U.S. gross energy input increases at 3.2% over the 1975-80 period, at 3.1% over 1980-85 and at 2.9% over 1985-2000.

The composition of total energy input is also expected to change markedly. Coal is projected to decline slightly in relative importance until 1985 but then to increase until 2000 as new demand for coal for synthetic gas production is super-imposed on the continuing demand for coal for electricity generation. The net result is that the share of coal in total input is almost the same in 2000 as in 1975. Petroleum shows a continuing decline in relative importance. Use of petroleum continues to increase at around 2.75% a year until 1985 but this increase gradually slows as the introduction of more energy efficient capital and change in economic patterns have their principal effects in reducing demand for petroleum. For example use of more efficient automobiles, more use of public transport, better building insulation, use of heat pumps in heating and cooling all have a major effect in slowing the increase in petroleum use. Thus, by 2000, petroleum is projected to form 36% of total energy input, compared to 44% in the 1970's.

Natural gas is predicted to decline dramatically in relative importance. This is due primarily to expected supply limitations which prevent its use from keeping pace with the other fuels. The share of natural gas in total energy falls from 33% in 1975 to 18% in 2000 (although, in terms of consumption, synthetic gas supplements the availability of gaseous fuels). Finally, the hydro, nuclear and other share in total input is expected to increase dramatically. This is due to the rapidly increasing use of electricity and to the steadily increasing importance of nuclear generation within the electricity sector. The 9% average annual increase of hydro and nuclear input over the 1975 to 2000 period results in its share in total input increasing from 7% to 29%.

Consumption of each type of energy is shown in Table 8. Coal consumption increases at an average rate of 2.7% over the 1975-2000 period, petroleum consumption at a rate of 2.1%, electricity at 5.2% and gas (natural plus synthetic) at 1.1%. These growth rates vary within the period, typically increasing over the 1975-80 period, compared to rates for 1970-75, which are reduced as a result of the 1973-74 energy crisis. After 1980 the growth rates steadily decline over the remainder of the century. The dominant trend in these aggregate consumption figures is the continued rapid increase in electricity consumption.

The rapid increase in electricity use has several implications. First, since electricity is a secondary form of energy suffering large energy losses in the conversion from primary fuels, it is very expensive in terms of energy input and its rapid growth produces a rapid growth in the use of primary fuels. In other words, the cost of the electricity growth in energy terms is the absorption of ever increasing proportions of total energy input in electricity conversion loss. For example, in 1975 electricity con-

Table 8. U.S. Energy Consumption, 1970-2000.

	1970	1975	1980	1985	2000
1. U.S. Energy Consumption (Quadrillion Btu)					
Coal	12.922	13.262	14.304	16.538	26.891
Petroleum	29.614	33.902	39.176	44.547	58.148
Electricity	5.218	6.781	8.854	11.499	23.873
Gas	22.029	24.506	26.888	28.835	32.321
2. Energy Consumption, Growth Rates (Average percent per annum)					
Coal		0.52	1.52	2.94	3.29
Petroleum		2.74	2.93	2.60	1.79
Electricity		5.38	5.48	5.37	4.99
Gas		2.15	1.87	1.41	0.76
3. Energy Consumption, Physical Units					
Coal (Million short tons)	525	573	618	715	1163
Petroleum (Million barrels a day)	14.70	16.83	19.44	22.11	28.86
Electricity (Billion kilowatt hours)	1530	1984	2590	3363	6981
Gas (Trillion cubic feet)	21.37	23.63	25.90	27.76	31.10

Note: Coal consumption includes coal used in electricity generation and in the production of synthetic gas. Petroleum consumption includes petroleum inputs into electricity generation and synthetic gas. Gas consumption includes both natural and synthetic gas.

version losses are projected to amount to 14.2 quadrillion Btu, or 18.4% of total energy input, but in 2000 these losses are projected to be about 50.0 quadrillion Btu which is 31.0% of total energy.

The second implication of electricity use is derived from the fact that any fuel can be used as the primary input to electricity generation. Uranium and hydro resources, at present, have no alternative use, although uranium enrichment for present generation nuclear reactors is a heavy user of electricity. Also, the ability to use any fossil fuel gives electricity generation some degree of comparative advantage over final use of these fuels. Electricity generation can exploit coal, which is in relative abundance in the U. S., and residual oil, which, for technical reasons, has only limited value as a fuel in other uses. In short, electricity has a property that partially offsets its large energy requirements for the cheapest and most abundant fuels can be used in its generation, leaving scarce oil and gas supplies available for direct use.

Projected fuel prices are shown in Table 9. All prices are expected to increase in current dollars, coal by an average of 6.5% a year over the 1975-2000 period, crude petroleum by 4.5%, refined petroleum products by 5.8%, electricity by 3.0% and gas by 6.7%. These rates of increase reflect both supply and demand factors. The rapid increase in coal prices is due largely to the slow productivity advance expected in the coal mining industry; increasing difficulty and expense in securing crude oil both domestically and from foreign sources, combined with demand conditions in petroleum product markets, operate to produce continuing rapid increases in oil prices; electricity prices increase but, due to continued productivity advance in the electric utilities sector, at a much slower rate than other prices; gas prices rise rapidly as an increasing demand faces a relatively inelastic supply (this presupposes a relaxation of price controls on natural gas).

When the rates of increase of fuel prices are compared to general inflation, which averages 3.8% over the 1975-2000 period, a somewhat different picture emerges. First, coal, petroleum and gas prices all show a significant increase in real terms, which is in marked contrast to historical experience, e.g. between 1951 and 1971 real coal prices fell 15% and real prices for refined petroleum products fell 17%. This rising price trend provides a strong incentive for economy in the use of fossil fuels. The second price feature is that electricity prices, in real terms, fall slightly although the 17% fall between 1975 and 2000 is again much less than the 43% fall that occured between 1951 and 1971. Compared to past experience, the slower decline in real electricity prices exerts some pressure to slow the historical rate of increase in electricity use, but the main effect of the real electricity price decline is to continue to promote the substitution of electricity for other fuels.

The fuel supply sections of the energy forecasts are shown in Table 10. Although our interindustry model takes account of production and supply possibilities after the primary extractive stage it does not include any detailed information on the supply characteristics of the U. S. fuel extracting industries. Indeed, given current knowledge, any supply side predictions, particularly to 2000, are hazardous. The supply figures shown in Table 10 represent, essentially, estimates appended to the model. Coal has no supply

Table 9. U.S. Energy Prices, 1970-2000.

	1970	1975	1980	1985	2000
1. Fuel Prices, Current Dollars					
Coal ($/short ton)	7.59	11.48	16.38	22.84	54.83
Crude Petroleum($/barrel)	3.39	7.12	8.64	10.97	21.20
Electricity (¢/kilowatt hr.)	1.61	2.06	2.40	2.78	4.30
Gas($/thousand cubic ft.)	0.83	1.00	1.48	1.97	5.03
2. Fuel Prices, Growth Rates (Average percent per annum)					
Coal		8.63	7.36	6.88	6.01
Crude Petroleum		16.00	3.95	4.89	4.49
Electricity		5.05	3.10	2.98	2.95
Gas		3.80	8.16	5.89	6.45
GNP Price Deflator		5.63	4.11	3.70	3.66
3. Fuel Prices, Constant Dollars					
Coal ($1975/short ton)	5.77	11.48	13.39	15.57	21.80
Crude petroleum($1975 /barrel)	4.46	7.12	7.06	7.48	8.42
Electricity (¢1975/kilowatt hr.)	2.12	2.06	1.96	1.90	1.71
Gas($1975/thousand cubic ft.)	1.09	1.00	1.21	1.34	2.00

Table 10. Energy Supply, 1970-2000.

	1970	1975	1980	1985	2000
Coal (Million short tons)					
Production	598	658	707	819	1291
Exports	72	85	89	104	129
U.S. Consumption	525	573	618	715	1163
Petroleum (Million barrels a day)					
U.S. Crude Output	11.54	10.69	13.91	17.82	21.41
(including gas liquids)					
U.S. Output of Shale Oil	0	0	0	0	4.29
Imports	3.42	6.40	5.78	4.51	3.28
U.S. Consumption	14.70	16.83	19.44	22.11	28.86
Exports	0.26	0.25	0.24	0.23	0.12
Gas(Billion cubic feet)					
U.S. Output of Natural Gas	20616	21493	22510	23620	23812
U.S. Output of Synthetic Gas	0	0	0	664	3502
Imports	821	2210	3443	3525	3813
U.S. Consumption	21367	23629	25898	27762	31097
Exports	70	74	55	47	30
Total (Quadrillion Btu)					
U.S. Energy Input	67.444	77.186	90.484	105.326	161.241
Exports	2.610	2.554	2.601	2.905	3.256
Total Demand	70.054	79.740	93.085	108.231	164.497
Imports	8.235	17.224	17.331	14.527	12.174
Supplemental (synthetic gas, shale oil)	0	0	0	0.690	12.281
Imports as Percentage of Total Demand	11.76	21.60	18.62	13.42	7.40
Supplemental as Percentage of Total Demand	0	0	0	0.64	7.47

problems concerning its existence, the only problems concern the prices at which mining and land reclamation become economic. Our coal supply information represents an extrapolation of past data and is embodied in the coal sector production structure of the model. The U. S. oil output figures are based on an ad hoc combination of past price elasticities and current information concerning future oil fields, such as the North slope and other Alaskan fields. Imports make up the difference between U.S. demand and supply at each oil price. Our estimates for U. S. output of natural gas are based upon estimates made by various government and private agencies, as are our estimates for the output of synthetic gas and of shale oil.

The energy flows forecast for the 1975-2000 period are presented in detail in Table 11 and in summary form in Table 12. The inter-industry energy flows are shown in trillions of Btu for each of the four fuels -- coal, petroleum, electricity, and gas -- into each of the nine intermediate and four final use sectors. These Btu flows are obtained by applying exogeneous Btu/constant dollar ratios to the fuel entires in the constant dollar transaction matrices.

Since we are operating at a greater level of disaggregation of fuel uses than is given in energy data, it was necessary to make some simplifying assumptions to obtain the translation of dollars to Btu's

Information is available for the Btu/constant dollar ratio for each fuel and this ratio for fuel inputs to electricity generation can also be accurately derived from published data. Thus, there is no problem in deriving the figures for total use of each fuel or for fuel inputs into electricity. To fill in the remaining Btu entries it was assumed that, within each fuel, the same Btu/constant dollar ratio applied to each remaining entry with certain exceptions. The exceptions, which embody what other information is available, are that sales of electricity to households and to agriculture take place at a price 67% above that charged other users, that petroleum products to households and to agriculture have, because of the product mix, a price 50% and 25%, respectively, above the average price charged other users, and that the price of gas to households in 1971 was $1.48/million Btu, the price to manufacturing was $0.56 and that gas prices to other users are equal.

Table 11. Composition of U.S. Energy Use, 1970-2000, Intermediate and Final Demand by Sector (all figures in trillion Btu).

	U.S. Output	Imports	Total Demand, Supply	Demand Energy Inputs to Sector 1	2	3	4	5	6	7	8	9	10	11	12	13
										Coal						
1970	14911	2	14913	27	3342	15	440	1223	0	17	7483	6	173	159	36	1991
1975	15208	9	15217	0	3106	0	64	1228	0	0	8725	0	102	4	33	1955
1980	16356	9	16365	0	3040	0	74	853	0	0	10227	0	74	4	33	2061
1985	18929	10	18939	0	2833	0	66	863	0	0	11818	844	75	4	34	2401
2000	29850	16	29866	0	3904	0	90	1316	0	0	15985	5504	43	7	43	2975
										Petroleum						
1970	22773	7388	30161	3830	4747	2614	3903	32	83	150	2087	148	10533	126	1360	547
1975	19787	14635	34422	4349	5614	3057	4383	34	51	127	2375	165	12115	79	1500	573
1980	26356	13302	39658	4897	6476	3696	5057	59	44	138	2567	197	14261	107	1677	482
1985	34600	10401	45001	5586	7575	4480	5931	94	29	160	2830	318	15555	125	1865	453
2000	50689	7706	58395	8244	11602	6210	9340	165	0	181	3918	625	15366	119	2379	247
										Electricity						
1970	5220	0	5220	101	1388	19	1459	21	44	43	596	0	1396	0	149	4
1975	6784	0	6784	122	1796	22	1891	29	46	31	671	0	1987	0	184	4
1980	8857	0	8857	173	2261	30	2248	40	73	14	835	0	2950	0	228	4
1985	11502	0	11502	150	2709	36	2910	61	119	0	928	0	4254	0	331	4
2000	23876	0	23876	245	4771	55	5487	180	227	0	1613	0	10697	0	597	4
										Gas						
1970	21255	846	22101	171	8884	281	1804	7	0	968	4015	595	4722	0	582	72
1975	22002	2580	24582	204	10088	347	2024	7	0	817	4245	599	5409	0	765	76
1980	22923	4020	26943	235	11389	414	1931	9	0	1231	4505	589	5716	0	869	55
1985	24766	4116	28882	278	13643	431	1742	13	0	1160	4856	568	5321	0	798	47
2000	27899	4452	32351	334	17425	450	1461	26	0	586	6473	475	4274	0	809	30

Table 12. Composition of U.S. Energy Use, 1970-2000, Summary.

		Use (Quadrillion Btu)			Growth Rates (average percent per annum)		
		Final	Intermediate	U.S. Total	Final	Intermediate	U.S. Total
Coal	1970	0.368	12.554	12.922			
	1975	0.139	13.123	13.262	-17.69	0.89	0.52
	1980	0.111	14.193	14.304	- 4.40	1.58	1.52
	1985	0.113	16.424	16.538	0.36	2.96	2.94
	2000	0.092	26.799	26.891	- 1.36	3.32	3.29
Petroleum	1970	11.435	18.179	29.614			
	1975	12.664	21.238	33.902	2.06	3.16	2.74
	1980	14.528	24.648	39.176	2.78	3.02	2.93
	1985	15.913	28.634	44.547	1.84	3.04	2.60
	2000	16.125	42.022	58.148	0.09	2.59	1.79
Electricity	1970	1.427	3.791	5.218			
	1975	2.154	4.627	6.781	8.58	4.07	5.38
	1980	3.052	5.802	8.854	7.23	4.63	5.48
	1985	4.379	7.120	11.499	7.49	4.18	5.37
	2000	11.047	12.826	23.873	6.36	4.00	4.99
Gas	1970	4.399	17.630	22.029			
	1975	5.040	19.466	24.506	2.76	2.00	2.15
	1980	5.488	21.400	26.888	1.72	1.91	1.87
	1985	5.218	23.617	28.835	-1.00	1.99	1.41
	2000	4.553	27.768	32.321	-0.90	1.09	0.76

Coal is used primarily in manufacturing, coal mining, electricity generation and for export. The first two uses are relatively unchanging; the projected growth in coal consumption comes in its use in electricity generation, its use for export and, in the latter part of the forecast period, as an input to synthetic gas. The summary table brings out the fact that coal is entirely used as an intermediate fuel and that its use is projected to increase at an increasing rate.

Petroleum products are used heavily in all sectors. Here, growth rates are projected to differ sharply for the demand for petroleum in final use increases only slowly while intermediate demand continues to increase rapidly. Use of petroleum products in all intermediate sectors continues to increase at similar rates, with the average increase being 3.0% in the 1975-85 period, then falling to 2.6% from 1985-2000. Final demand, particularly for personal consumption use, grows much more slowly, rising to a peak in the mid 1980's and then remaining steady over the rest of the forecast period.

The slow growth of final demand is due to various factors - higher petroleum prices and the conservation ethic stimulating economy in use of petroleum, the incorporation of energy saving devices such as more building insulation, heat pumps, more efficient heating units, into the capital stock of buildings, the replacing of large cars by more energy efficient vehicles, both smaller cars and more public transport, the substitution of electronic communication for some purposes presently achieved by moving people, and the increasing use of electricity in the home partially replacing petroleum. The time involved in these changes is rather long for first attitudes must be changed, by economic, regulatory and other pressures, and then these attitudes must be translated into new capital stock which, typically, must wait upon the depreciation and replacement of the existing stock, or in some cases, such as building insulation, can be incorporated into existing, highly durable stock. In any event, a long time lag is predicted before the full effects of this conservation become felt in terms of reduced energy input but ultimately, in the 1980's and 1990's, the scope for conservation is large enough to permit increasing levels of effective services to be sustained from a constant input of petroleum energy.

Electricity consumption increases at a rapid rate - 5.2% a year between 1975 and 2000. The overall rate of increase steadily decreases, after an increase in the 1975-80 period compared to the previous five years, due to the 1975 consumption figure being depressed by the reaction to the current energy crisis. As in petroleum use, final and intermediate demand components grow at different rates but, as with electricity, it is final demand that grows more rapidly. Intermediate use of electricity increases at an average of 4.2% a year with use in the services sector increasing the

most rapidly, at 4.5%, and manufacturing use increasing at 3.9%. Final use of electricity increases at 6.8% a year with the most rapid increase taking place in personal consumption which increases at 6.9% a year over the 1975-2000 period. This use of electricity in personal consumption forms the most rapid increase of any use of any fuel and, in this, continues the same trend that has been observed in the past. The rate of increase is slower than that of the past due to the different price behavior, the new awareness in energy conservation, the introduction of more energy efficient capital such as heat pumps and thermal insulation, and the approach to saturation of such heavy electricity users as home air conditioning, dishwashers, laundries, ranges and so on.

Gas consumption is forecast to increase comparatively slowly and at a declining rate. Increasing use of gas is limited to two sectors -- manufacturing and electricity generation, with use in other sectors, primarily services and personal consumption, declining. The net result is that final demand for gas declines, but intermediate demand continues to increase, although at a declining rate. The projected price increases for gas reduce its use in service and final use sectors, where its place is taken by petroleum and electricity, but gas remains important as an input into manufacturing and to electricity generation because of its nonprice advantages -- it is clean burning, easily handled and it has many uses as a material, rather than a fuel, input.

The composition of inputs into the electricity generation sector is shown in Table 13. The dominant

Table 13. Composition of Inputs to U.S. Electricity Generation, 1970-2000 (Percent of total input)

	1970	1975	1980	1985	2000
Coal	45.4	41.6	37.3	33.2	21.6
Petroleum	12.7	11.4	9.4	7.9	5.3
Gas	24.4	20.8	16.4	13.6	8.8
Hydro, Nuclear, other	17.5	26.3	36.9	45.2	64.3

feature here is the projected increase in hydro and nuclear, virtually all the increase being in nuclear, generation. In 1970 hydro and nuclear provided 17.5% of total input but this proportion increases to 64% by 2000. Coal input, although growing rapidly in absolute terms, declines in relative importance as an input from supplying almost half of total inputs in 1970 to one-fifth in 2000. Similarly, although petroleum and gas inputs increase in absolute terms, this increase is relatively slow and they show a steady decline in proportion to total input.

The changing composition of inputs into electricity generation reflects relative prices and is undertaken by the electricity generation sector in response to market forces. But, these forces also reflect, in part at least, a basic characteristic of U. S. fuel supply possibilities. Coal, uranium and hydro power are not only relatively abundant but also have a low economic opportunity cost for, apart from electricity absorbed in uranium enrichment, they have comparatively few alternative uses, whereas petroleum and gas fuels are not only in relatively short supply but also have many alternative uses that render their opportunity cost, for use in electricity generation, very high. In these respects, and omitting nuclear safety from consideration, the forecast outcome of market forces, as they affect inputs to electricity generation, appears to be entirely consistent with the objectives of currently proposed national energy policies.

5. ENERGY POLICY: A BTU TAX

5.1 Introduction. This section describes the application of the inter-industry energy model to the analysis of one specific energy policy--a Btu tax designed to secure energy independence. This application serves to illustrate the methodology of the model and provides an evaluation of a specific tax proposal currently under consideration. The actual tax considered is a uniform rate of tax levied on the energy content of all fuels used outside the energy generation sector; such a tax is proposed in the Energy Revenue and Development Act of 1973, at present under consideration in the Senate Finance Committee.[26]

The starting point for the analysis of this tax is the base case set of energy projections which have been presented above. These projections are based on the assumption of no major new developments in energy policy and so can be used as a reference point against which the changes induced by policy changes are measured.. In particular, the fuel imports in these forecasts define the objective of the policy, which is to reduce these imports to nominal levels by a target date, which we take to be 1985.

The tax has the effect of creating a wedge between the price paid by the energy consumer and that received by the producer. Since the forecast supply prices already equal average costs, the tax is translated into an increase in the fuel selling price, leaving the supply price unchanged, apart from indirect impacts on the supply price due to any production cost increases that are caused by the tax. Therefore, the tax leads to the reduction of fuel imports solely by acting on the demand side of the energy equation. This approach is the opposite of much of the present de-

bate about energy policy, which is supply oriented. It emerges that demand based policies can be extremely effective and have the power to produce energy independence even without accompanying supply expansion policies.

The Btu tax is inserted into the model by means of price markups that increase the sales prices of fuels above the output price received by the seller. These markups vary for the five fuels since the Btu content of each dollar of fuel output is different for each fuel (the cost of Btu's obtained from the various fuels are given in Table 16). The tax is assumed to be levied only on energy as it emerges from the fuel sectors so that energy inputs into fuel production, including the generation of electricity, are not subject to tax. Also, exports of fuels, mainly coal, are considered exempt from the tax.

After price markups have been inserted, the model is solved to obtain a new set of economic and energy projections. This involves solving for new output prices and input-output coefficients, new final demand components, and the associated industry output levels and inter-industry transactions. This information is then used to determine the energy deficits--the excess of U.S. demand for each fuel over the domestic output, both being calculated in terms of the new set of prices--which must be made up by fuel imports. This procedure captures both the direct and indirect effects of energy conservation--the direct saving of energy as an input by the substitution of other inputs for energy as well as the indirect saving of energy produced by substituting, in production and consumption, nonenergy intensive for the energy intensive goods and services.

5.2 Tax policy and conservation. We proceed in two steps, first examining the effects of the Btu tax by assessing the impact of various rates of tax on the energy and nonenergy sectors of the economy in 1980 and second, considering the specific tax structure that would be required to achieve the objective of independence from energy imports by 1985. The definition of energy independence used is for zero imports of gas and for only nominal imports of petroleum, such as would be required for fueling of U.S. aircraft and ships abroad. An arbitrary limit of one quadrillion Btu of energy imports was adopted for 1985; this limit is less than 10% of actual 1973 fuel imports.

The impact on energy use, of various rates of Btu tax is summarized in Table 14. These figures show that the Btu tax can induce significant reductions in energy use and that it has the potential for reducing demand sufficiently to secure energy independence. The highest rate shown, $0.5 per million Btu, leads to a decline of 7 quadrillion Btu, or 7.8%, in energy use

Table 14. Impact of Btu taxes on Total Energy Input, 1980.

Tax Rate ($/million Btu)	0	0.1	0.3	0.5
Total Energy Input (Quadrillion Btu)	90.483	88.890	86.004	83.440
Change from Base		-1.593	-4.479	-7.043
Change/Tax Rate		-15.93	-14.93	-14.07
Percent change from base		-1.76	-4.95	-7.78
Intermediate Use (Quadrillion Btu)	70.356	69.321	67.415	65.692
Change from base		-1.035	-2.941	-4.664
Change/Tax rate		-10.35	-9.80	-9.33
Percent change from base		-1.47	-4.18	-6.63
Final Use (Quadrillion Btu)	20.127	19.569	18.589	17.748
Change from base		-0.558	-1.538	-2.379
Change/Tax rate		-5.58	-5.13	-4.76
Percent change from base		-2.77	-7.64	-11.82
Energy Imports (Quadrillion Btu)	17.331	15.644	12.832	10.392
Imports in total input (1%)	19.2	17.6	14.9	12.5
Tax Revenue ($ billion)	0	6.026	17.400	28.003

relative to the no tax projection. This reduction is made up of substantial cuts in both final and intermediate uses of energy. The greater part of the reduction comes from the decline in energy input to intermediate production but the relative cutback in use is greater in final demand where energy input is reduced by 11.8%, compared to the 6.6% fall in intermediate use.

Our results indicate that although final users of energy may be more responsive to price increases than business users, the sheer volume of energy absorbed in production requires that, for maximum effect, energy conservation policies give at least as much weight to reducing intermediate as to reducing final demand. The response of both intermediate and final users to the tax varies with the tax level with, in both cases, the tax having a diminishing marginal impact on energy use. The decline in effectiveness is, however, gradual so that a reasonable first approximation is that each dollar of tax per million Btu's reduces total energy input by about 15 quadrillion Btu. This corresponds to an elasticity of Btu use to Btu price of approximately -0.24.

The detailed adjustments by energy users to the imposition of the tax are shown in Table 15. These figures show, first, the different degrees of energy conservation in the four major energy consuming sectors--manufacturing, services, electricity generation and personal consumption. Substantial economies are made in the energy input to each sector but there is a wide difference in the proportionate response: energy used in personal consumption is reduced by 9.5% in response to the $0.5 tax rate, with services use being cut by 7.1%, manufacturing use by 5.8% and input into electricity generation by 2.1%.

Energy use can be split into two broad categories --discretionary use and process use. Discretionary use includes inputs for comfort functions such as heating and cooling as well as personal services such as auto-

Table 15. Impact of Btu Taxes on Input Patterns, 1980.

Tax Rate ($ /million Btu)	0	0.1	0.3	0.5
Energy input, including use of electricity (Quadrillion Btu)				
Manufacturing	18.908	18.669	18.222	17.809
Services	10.496	10.335	10.032	9.752
Electricity generation	27.403	27.289	27.063	26.840
Personal consumption (including use of electricity)	20.474	20.025	19.224	18.527
Percentage change in total inputs:				
Energy input		-1.76	-4.95	-7.78
Capital input		0.11	0.29	0.49
Labor input		0.14	0.39	0.61
Input-output coefficients for total energy inputs:				
Agriculture	0.0245	0.0239	0.0226	0.0216
Manufacturing	0.0235	0.0233	0.0232	0.0231
Transport	0.0447	0.0440	0.0426	0.0413
Services	0.0190	0.0189	0.0186	0.0183
Electricity generation	0.1864	0.1859	0.1850	0.1844
Input-output coefficients for manufacturing				
Coal	0.0026	0.0026	0.0025	0.0025
Petroleum	0.0069	0.0068	0.0068	0.0067
Electricity	0.0085	0.0086	0.0087	0.0088
Gas	0.0055	0.0054	0.0052	0.0051
Total energy	0.0235	0.0233	0.0232	0.0231
Capital services	0.1201	0.1200	0.1199	0.1198
Labor services	0.2887	0.2889	0.2893	0.2897
Materials input	0.5164	0.5163	0.5162	0.5160

mobile travel. Process use covers fuel inputs for driving machinery, heating materials, turning generators and so on. Discretionary uses are, typically, characterized by greater flexibility than process uses firstly because the associated capital stock is generally less durable and easier to replace with more energy efficient capital, and secondly because discretionary uses are input to the generation of psychologically rather than technically specified performance, e.g., desired miles driven rather than energy inputs required per ton of alumina to be smelted, so the level of use within the existing capital stock can be more readily varied. Given this categorization, it is apparent that personal consumption includes a high ratio of discretionary to process energy use while this ratio for service activity is a little lower, for manufacturing lower still and for electricity generation lowest of all. This ordering is precisely that observed in the sectoral response to the increase in energy prices.

More specifically, the input-output coefficients in Table 15 show the processes of adjustment to the tax induced increases in energy prices. Two types of adjustment can be seen. First, there is a substitution of the now relatively less expensive non-fuel inputs for the relatively more expensive fuel inputs. This is reflected in the total energy input coefficients which, for each sector, decline as the energy tax increases. The manufacturing input-output coefficients show the outcome of this substitution process: energy inputs decline, as do inputs of materials and inputs of capital with inputs of labor services increasing to replace the three reduced inputs. Thus, in manufacturing, energy-capital-materials complementarity means that adjustments to economize on the expensive energy input lead to the use of energy, capital and materials all being reduced and more labor intensive production techniques adopted.

The shift away from energy in manufacturing is relatively small in terms of changes in input-output coefficients, but it represents a substantial amount of energy. A similar process of substitution away from energy takes place in all sectors. The overall result, however, is a little different from that in manufacturing. The total reduction in energy use is made possible by an increase in inputs of both capital and labor. That is, on an economy wide basis, energy-capital substitutability, such as the use of insulation or smaller cars to save energy, dominates the complementarity relation that characterizes manufacturing. The net effect is that the 7.8% fall in energy input is accomodated by a 0.6% increase in the demand for labor and a 0.5% increase in capital use and does not result in a comparable reduction in potential output.

The second set of adjustments occurs within energy input as interfuel substitution takes place. The tax has the effect of increasing different fuel prices by different extents, depending on the energy content of each fuel. Coal prices are increased to the greatest extent, with gas prices next, then petroleum, with electricity prices being increased the least. The input-output coefficients for fuel use in manufacturing, shown in Table 15 illustrate the resulting substitutions. Coal use declines only slightly for, despite the sharp price increase, coal remains the cheapest source of energy as well as being, for technical reasons, used in some production, such as steel, regardless of the price changes. The petroleum and gas coefficients both decline more noticeably. Electricity use, however, increases since electricity has become a relatively less expensive fuel and since its flexibility in use permit it to substitute for petroleum and gas.

The impact of the Btu tax on the price and consumption of each fuel is shown in Table 16. Coal prices increase by the largest proportion, with the average increase of 28%, for the $0.5 tax rate, comprising a 70% increase in price to nonfuel purchasers and virtually no increase in price in fuel production or export uses. The gas price increases by 24% for the highest tax rate, with the wholesale price of refined petroleum products increasing by 23% and electricity prices rising by only 7%. The small price increase for electricity leads to a correspondingly small demand decline, only 2%. This small decline also implies that coal input into electricity, the main use of coal, declines by only a

Table 16. Impact of Btu Taxes on Energy Consumption and Prices, 1980.

Tax Rate ($ /million Btu)	0	0.1	0.3	0.5
Fuel Consumption (Quadrillion Btu)				
Coal	14.304	14.237	14.104	13.971
Petroleum	39.176	38.459	37.138	35.940
Electricity	8.854	8.817	8.744	8.672
Gas	26.888	26.126	24.791	23.650
Change in Consumption from Base (%)				
Coal		-0.47	-1.40	-2.33
Petroleum		-1.83	-5.20	-8.26
Electricity		-0.42	-1.24	-2.06
Gas		-2.83	-7.80	-12.04
Average Fuel Prices				
Coal ($ /ton)	16.38	17.31	19.16	21.02
Refined Petroleum ($ /barrel, wholesale)	11.84	12.38	13.46	14.55
Electricity ($ /Kwhr)	0.0241	0.0244	0.0251	0.0257
Gas ($ / th cu ft)	1.48	1.55	1.70	1.84
Change in Prices from Base				
Coal		5.68	16.94	28.33
Refined Petroleum		4.57	13.71	22.85
Electricity		1.32	3.96	6.60
Gas		4.87	14.62	24.36
Price of Energy to Taxed Users ($ /million Btu)				
Coal	0.71	0.81	1.01	1.21
Petroleum	2.21	2.31	2.51	2.71
Electricity	7.02	7.12	7.32	7.52
Gas	1.42	1.52	1.72	1.92

small proportion. The only other sizeable domestic use of coal is in the manufacturing sector, but this use is relatively insensitive to price as discussed above. The price of gas increases substantially and this, with the opportunities to economize in its use and to substitute other fuels for it, leads to a decline of 12% in its use. Similarly, petroleum prices rise substantially, causing a decline of 8% in the consumption of petroleum. The average price elasticities implied by these consumption responses are: -0.08 for coal, -0.36 for petroleum, -0.31 for electricity and -0.49 for gas.

The effects of the Btu tax are not restricted to the energy sectors. There are also effects on the input structure of other production, as have been outlined above, on the costs and prices of these other goods, on the demand for these goods in intermediate uses, and on the level and composition of real final demand. These effects are summarized in Table 17 which gives the tax induced changes in nonenergy prices and quantities demanded. All prices are increased as the effects of the higher fuel prices work through the production cost structure. The process of substitution towards the relatively less expensive inputs lessens the impact of the fuel price increases on average costs, but the net effect is still an upward movement in costs, and in prices in general.

The price increases by sector are in line with the importance of energy in the sector's inputs: transport prices increase the most, followed by agriculture and manufacturing, with service prices rising the least; this

Table 17. Impact of Btu Taxes on Non-energy Prices and Quantities, 1980 Percentage Change from Base Case.

	Price			Quantity		
Tax Rate ($ /million Btu)	0.1	0.3	0.5	0.1	0.3	0.5
Gross Output:						
Agriculture	0.17	0.51	0.82	-0.18	-0.53	-0.85
Manufacturing	0.16	0.50	0.82	-0.10	-0.30	-0.49
Transport	0.21	0.64	1.05	-0.17	-0.52	-0.84
Services	0.06	0.22	0.34	-0.08	-0.22	-0.36
Final Demand:						
Consumption	0.27	0.86	1.34	-0.12	-0.33	-0.53
Investment	0.16	0.48	0.74	-0.11	-0.31	-0.51
Government	0.12	0.38	0.56	-0.08	-0.22	-0.36
GNP	0.23	0.69	1.07	-0.09	-0.26	-0.42

ranking is the same as the ranking of these sectors in terms of energy input-output coefficients. The price increases are not, however, very sizeable. Even for the $0.5 tax rate, the price increases range from 0.34% for services to 1.05% for transport. Similarly, the aggregate consumption price index and the GNP price deflator increase by only about 1% since the small nonenergy price rises dominate the larger fuel price increases in these price indices. The quantity changes induced by the energy tax are correspondingly small. The new prices, and the decline in real incomes, lead to a reduction and redirection of real final demand, but the resulting change in total real consumption and real GNP are very small, only of the order of 0.5%.

Two alternative bases for the Btu tax were examined. These were the cases in which the tax was levied only on final consumption of energy and in which the tax was levied only on intermediate inputs to the nonenergy sectors. Both taxes do reduce total energy input, the final use tax by 2.8%, and the intermediate tax by 5.3% for a tax rate of $0.5 per million Btu. This compares with the 7.8% reduction for the general tax. Thus, although the energy conservation impact of a Btu tax diminishes as the base is restricted, even a tax on one of the narrow bases does lead to nonnegligible cutbacks in energy consumption. So, if political considerations were to preclude a final use tax the intermediate Btu tax could still play an effective role in an energy policy package.

5.3 Import independence. Our central conclusion is that a Btu tax can induce significant reductions in energy consumption, corresponding to even larger relative reductions in fuel imports, at the cost of comparatively minor changes in production patterns, prices or demand. Our next step is to apply these results to formulate a specific Btu tax program that would result in import independence by 1985. The tax rate required to reduce energy consumption in 1985 to a level that requires no fuel imports is $1.35 per million

Btu. The effects of this tax are summarized in Table 18. The revenue yield of this tax is $76.9 billion. This is a substantial withdrawal from the private spending stream and, unless returned through other policy measures, would have a significant deflationary impact. This revenue would be more than ample to sustain a major research and development effort on energy supply as well as to cover other government spending or to permit reductions in other taxes.

The reduction in energy use is secured through the effect of the tax in increasing fuel prices. In fact, a rise of around 40% in fuel prices, compared to the base case, is required to obtain the necessary cutback in energy use. Average coal prices are raised by 49% by the tax, gas prices are increased by 47%, petroleum prices by 42% and electricity prices by 15%. The induced reduction in fuel consumption range from 5% for coal and 6% for electricity, to 19% for petroleum and 24% for gas. The total reduction in energy input is 17.1 quadrillion Btu, which is 16.2% of the base case level. This reduction corresponds to a greater reduction in energy input per dollar of Btu tax rate than emerged from the 1980 simulations. The reason for this is the lags involved in responses to higher energy prices, particularly the lags involved in the replacement of capital stock with more energy efficient capital.

These reductions in fuel consumption are greater than are strictly necessary for energy independence. Coal and electricity suffer no supply deficit and reduction in the use of these fuels does not directly contribute to the independence objective. Gas use is cut back substantially by the tax, by much more, in fact, than the 10% reduction that would be required to eliminate gas imports. Thus, although the Btu tax does, fortuitously, induce conservation primarily in the two fuels whose consumption must be reduced if the independence objective is to be achieved, it is comparatively inefficient in achieving this objective for it is so broad in its effects that the tax rate required to achieve petroleum independence produces excessively large reductions in the use of other fuels. The application of a general instrument in pursuit of such a specific objective results in unnecessary economic cost. Since excess petroleum demand is the binding constraint in the independence objective, a specific petroleum tax would be a more efficient instrument.

The effects of the energy tax on the non-fuel sectors are not large. Prices increase by an average of only 2% for the large fuel price increases are dominated, in the consumption and GNP price indices, by the smaller increases in the prices of non-fuel goods. The input substitution processes, described above, permit production to accomodate the large reductions in energy input and the increases in fuel prices without corresponding decreases in output or increases in total costs.

The specific rate timetable of a Btu tax that would achieve energy independence by 1985 is a variable. The rate structure is subject to constraints, the rate must be zero in 1974 and $1.35 per million Btu in 1985, but the path between these end points is somewhat arbitrary. One possible rate timetable,, and its associated macro-economic effects, is presented in Table 19. But, if the Btu tax program were to be implemented, its rate structure should satisfy certain additional conditions. First the tax must be regarded as a permanent measure for, in the absence of other policies, continued energy independence requires that

Table 18. Impact of an Energy Independence Btu Tax, 1985.

Tax Rate ($ /million Btu)	0	1.35
Tax Revenue ($ /billion)	0	76.942
Total Energy Input (Quadrillion Btu)	105.326	88.244
Percentage Change from Base Case		-16.2
Imports of Petroleum (Quadrillion Btu)	10.401	0.975
Imports of Gas	4.116	0
Imports in Total Input (Percent)	13.8	1.1
Fuel Consumption (Quadrillion Btu)		
Coal	16.538	15.730
Petroleum	44.547	36.255
Electricity	11.499	10.780
Gas	28.835	21.926
Percentage Change in Fuel Consumption from Base Case		
Coal		-4.89
Petroleum		-18.61
Electricity		-6.25
Gas		-23.96
Percentage Change in Prices from Base Case		
Coal		49.15
Petroleum		42.20
Electricity		15.57
Gas		47.16
Agriculture		1.78
Manufacturing		1.70
Transport		1.98
Services		0.71
Consumption		2.41
GNP		2.04

Table 19. A Btu Tax for Energy Independence in 1985.

	1975	1980	1985
Btu Tax Rate ($ /million Btu)	0	0.5	1.35
Energy Input (Quadrillion Btu)	77.2	83.4	88.2
Energy Imports (Quadrillion Btu)		10.4	1.0
Revenue from Tax ($ billion)	0	28.0	76.9
Consumption of Energy (Quadrillion Btu)			
Coal		14.0	15.7
Petroleum		35.9	36.3
Electricity		8.7	10.8
Gas		23.7	21.9
Percentage Change from Zero Tax Case			
Real Consumption	0	-0.53	-1.22
Consumption Price	0	1.34	2.41
Real GNP	0	-0.42	-0.99
GNP Price Deflator	0	1.07	2.04

energy demand continually be depressed by taxes, and this will probably mean steadily increasing rates of tax. Second, the rate level should be increased fairly rapidly to the $1.35 level for, in view of the delays in incorporating energy conservation measures into production and final consumption, a high tax rate over much of the 1974-85 period would not only induce substantial conservation but would induce it early enough for its full effects to be felt by 1985. Third, it is desirable that the rate structure be known for several years into the future so as to reduce any economic incentive for delaying energy conservation in the hope that energy prices would fall in the future.

Our results show that a Btu tax can induce sufficient fuel conservation to secure energy independence by the mid 1980's. Further, it suggests that the cost of achieving this is not catastrophic. But it does not follow that this is the best or only means for securing independence. Arguments could be made for a policy mix that stimulated supply expansion as well as demand reduction. Also, arguments could be made for a mix of policies on the demand side, such as a Btu tax, regulations requiring building insulating, taxing of particularly heavy energy uses and so on. And it might be argued that a general policy, such as a Btu tax, is inefficient for it reduces demand for all fuels when the critical problem is evidenced only in petroleum. More fundamentally, the desirability and definition of energy independence could be debated ad infinitum. Our results beg the question of underlying objectives but they do indicate that the Btu tax does provide a means of securing energy independence.

6. CONCLUSION

We conclude with a brief overview of our methodology, comparing our framework for the analysis of energy policy with alternative approaches. Our model replicates each of the components of the overall transactions flow--purchase of primary inputs, sales of goods and services between sectors, formation of product prices and purchase of output by final users. These aspects of economic activity are brought into consistency by means of simulated market processes. All decision units react to the same set of prices and prices and quantities adjust so that all markets are cleared and each production sector covers its costs. The heart of the model lies in a series of submodels of production behavior, one for each of the nine domestic producing sectors. This set of production relationships provides the basic information used to determine relative output prices and the corresponding set of input patterns.

The sectoral production models are based upon price possibility frontiers. Within each sector, the price frontier expresses output price in terms of the prices of inputs and the production efficiency of that sector. Each frontier contains first and second order terms so that both the average requirements for each input and the interrelationships between inputs are captured. Thus, although the specification is in terms of prices, it captures the same information concerning input requirements, complementarities and substitutabilities as the more traditional production function.

The primary input prices are generated within our macro-econometric growth model. Productivities are exogenous to the producer submodels so the nine sectoral output prices can be solved from the nine price price frontiers. The simultaneous determination of prices permits the derivation of a set of prices for all produced output which not only takes account of production constraints and inter-relationships and primary input prices but also integrates all these price determinants into a consistent framework so that all sectors are simultaneously charging the minimum price that covers all their costs, including a return to capital. In short, given primary input prices and underlying production information, the model finds the equilibrium price system for the economy.

This approach to prices and production also permits the input pattern for each sector that is best suited to the prevailing set of prices and costs to be chosen from the infinity of patterns that are possible. Thus, producers can react to the prevailing structure of relative prices by adjusting their input patterns and substituting, within the limits set by the complementarity and substitutability information contained in the price frontiers, relatively less expensive for relatively more expensive inputs. In this way, a critical feature of the economy, the response of input patterns to prices, is systematically included in our model. This feature of the model is very important from a practical point of view in accommodating the detailed operation of the price system. Conceptually, it frees input-output analysis from the assumption of fixed coefficients, and extends input-output analysis by making the coefficients variable and by making them fully endogenous and linking them to price behavior.

After the analysis of production relationships has been completed, the next step in implementing our model is to examine the components of final demand. These components are produced by three final demand submodels. The initial inputs into these submodels are the prices charged for the output of each of the domestic producing sectors, the prices of primary inputs that enter directly into final use, and the total current dollar expenditures in three of the final demand categories--personal consumption, private investment and government purchases. These expenditure totals

are produced by the use of our macro-econometric model of U.S. economic growth. Our growth model provides levels of relative prices of consumption, investment, capital and labor within the framework employed to generate final demand in real terms. The model represents a major extension of macro-econometric model building to incorporate elements of both aggregate demand and aggregate supply.

We begin with the set of prices that is consistent with equilibrium demand and supply and with the levels of prices of primary inputs. We find the pattern of input-output coefficients associated with this price regime. We determine the level and composition of final demand that is associated with these prices. The input-output coefficients have been determined already, so the balance equations of input-output analysis are sufficient to find, in constant dollar terms, the total sectoral outputs and the pattern of industry purchases and sales necessary to sustain the final demand. This step imposes a final set of market clearing relationships on our simulated economy with the condition of equality between real demand and supply of every commodity being added to the condition of equality between value of demand and supply and of equality between receipts and expenditures for every sector.

The output from the inter-industry model comprises prices for each of the supplying sectors, the matrix of constant dollar transactions for the entire structure, and, by combining these two elements, the matrix of current dollar transactions. The transactions matrices cover the whole economic structure--energy as well as non-energy sectors. The energy information contained in these transactions matrices is already extensive, covering both volumes and prices. It can readily be extended, however, to produce the data forms traditionally used in energy analysis--energy flows in British Thermal Units, energy flows in physical units, and energy prices in terms of physical units. This further information for Btu's can be generated by inserting known values of the Btu content per constant dollar of each fuel, the volume in physical units can be obtained by using known physical unit per constant dollar ratios, and fuel prices can be generated by applying the base period prices to the price indices simulated in the model.

We conclude this overview of our framework for energy policy analysis by comparing the conceptual properties of our model with those of the traditional energy balance approach to energy analysis. The fundamental advantage of our approach is that, rather than viewing energy in isolation, it is viewed as one of the many interacting parts that make up the economic system. This perspective permits the systematic analysis of all the factors that influence energy on both demand and supply sides and, equally important, it permits the explicit linkage of energy developments to those variables, such as employment, incomes and consumption, that are ultimate ends to which energy use is only a means.

More specifically, our model incorporates the influence of fuel prices on the level and composition of energy use, and, further, it incorporates the effects of the level and pattern of nonenergy activity on energy use as well as the reverse linkage of energy prices and supplies to nonenergy price input, output and consumption patterns. These interrelationships are critical and it is essential, for both forecasting and policy purposes, to recognize them. Some examples of these linkages are the severe impact of the recent oil shortages on the output of and the incomes generated by the automobile and tourist industries, the implications for energy use of the secular trend of demand towards service activities, and the economies in fuel use induced by the recent increases in fuel prices.

One aspect of these linkages in which our model represents a particularly important advance over energy balance procedures is the variation of input patterns in response to relative prices. This is of great importance in energy analysis in view of the widespread ability to substitute between fuels, for example between coal and oil in electricity generation, between oil and gas in industrial heating, between gas and electricity in home cooking and so on. This substitution is not merely a matter of switching fuels for the associated capital stock must also be changed to permit the use of a different fuel. Our production models, by treating all inputs simultaneously, take account of the possibilities for both inter-fuel substitutions and substitutions of fuel for non-fuel input, but do this in such a way that the constraints implied by complementarities between inputs are recognized, so that a consistent analysis of the entire input picture is obtained.

Our investigation of the effects of a Btu tax serves to demonstrate the usefulness of our framework for energy policy analysis. The basic properties of the model are illustrated by the result that, in the 1980 simulations for example, energy input can be reduced by 8% at the cost of only a 1% increase in average prices and a 0.4% decrease in real income. In other words, the flexibility of the economy in adapting to changing resource availabilities and the power of the price system in securing this adaptation, mean that substantial reductions in energy use can be achieved without major economic cost. The analytical property of our model that incorporates this flexibility is the endogenous formation of prices and the endogenous determination of the response of production patterns and final demand to these prices. Also, the integration of

the various components of the model by means of interindustry analysis secures an overall consistency in the simulation of the market process. These features, permitting price formation and the reaction of producers and consumers to price chamges, combined in a simultaneous model of the entire economy, represent a major advance over traditional inter-industry and energy balance analysis.

FOOTNOTES

1. The seminal contribution to macro-econometric modeling of the U.S. economy is the Klein-Goldberger (1955) model. For a recent review of macro-econometric models of the United States, see Hickman (1972).
2. For the original development of input-output analysis, see Leontief (1951). A recent compendium of research on input-output analysis is Carter and Brody (1970).
3. A more detailed presentation of our approach is contained in Jorgenson, Berndt, Christensen, and Hudson (1973).
4. In the Klein-Goldberger model the determination of prices can be completely suppressed with a resulting improvement in forecasting accuracy for real magnitudes. See Suits (1962) and Goldberger (1959).
5. The energy balance framework has been employed by Dupree and West (1973) and The National Petroleum Council (1971, 1972).
6. Energy imports are significant only for crude and refined petroleum products, and natural gas. For the period 1958-1972 petroleum imports were subject to a system of quotas. Natural gas imports are subject to regulation by The Federal Power Commission. For a discussion of the petroleum import quota system, see Barrows and Domencich (1970).
7. For a detailed interpretation of the price possibility frontier, see Christensen, Jorgenson and Lau (1973), esp. pp. 32-33.
8. See Samuelson (1966).
9. For further discussion of the model of producer behavior, see Section 3, below.
10. The idea of treating input-output coefficients as functions of prices can be traced to Walras (1954), esp. pp. 382-392; this approach has been extensively discussed by Samuelson (1966), pp. 513-536, and Morishima (1964), pp. 54-92. A more influential idea is to model trends in input-output coefficients without treating them as part of a model of producer behavior. This alternative approach has been employed by Leontief (1953), Carter (1970) and Almon, et al. (1974). Comparisons of input-output coefficients for 1947, 1958 and 1961 are given by Carter (1970) and Vaccara (1972).
11. For a detailed discussion of the indirect utility function, see Christensen, Jorgenson, and Lau (1974).
12. This Section is based on Berndt and Jorgenson (1973).
13. See Christensen, Jorgenson, and Lau (1973), pp. 29-32.
14. See Leontief (1947).
15. See Christensen, Jorgenson, and Lau (1971).
16. A KLEM model for total U.S. manufacturing based on the translog price possibility frontier has been developed by Berndt and Wood (1974). Berndt and Christensen (1973, 1974a, 1974b) have developed models of capital-labor substitution for U.S. manufacturing based on the translog production function, which is dual to the translog price possibility frontier.
17. Methods for imposing convexity restrictions have been developed by Lau (1974).
18. These data were compiled by Jack Faucett Associates (1973).
19. The minimum distance estimator for non-linear simultaneous equations is discussed by Malinvaud (1970), pp. 325-373.
20. See, for example, the discussion of the neo-classical two sector growth model by Bermeister and Dobell (1970) and the references given there. A more detailed discussion of our model is presented in Hudson and Jorgenson (1974); see also, Jorgenson, Berndt, Christensen, and Hudson (1973), Chapter 2.
21. Detailed projections are presented by Hudson and Jorgenson (1974b).
22. Our model of the household sector was originated by Christensen and Jorgenson (1968). Our model of the business sector was originated by Christensen, Jorgenson, and Lau (1973).
23. The data are presented in a series of articles by Christensen and Jorgenson (1969, 1970, 1973a, 1973b).
24. The conversion process is discussed in the following section.
25. See footnote 5, above.
26. This section is based on Hudson and Jorgenson (1974a), presented as testimony at hearings by the Senate Finance Committee, January 16, 1974.

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SUMMARY OF DISCUSSION

The effects of imposing specific taxes on energy consumption were discussed. The model results show a substitution of labor for energy inputs. The plausibility of this result was questioned. It was pointed out that this substitution may be achieved by the movement from energy intensive products, such as aluminum, towards more labor-intensive products, such as wood, as well as by direct substitutions between energy, capital, and labor inputs.

Ideas for extending the model were discussed. It is planned to incorporate actual energy resource supply functions into the model and to disaggregate the nine sectors. The advantages and disadvantages of disaggregation were discussed. Disaggregation gains detail and a closer relation to specific activities of interest to policy analysts but it is achieved at the cost of building complexity and rigidity into the model so, when long term projections are involved the forecasts become more tenuous as confidence that the more detailed relationships will continue to hold is reduced.

Because the model is an equilibrium model, it is not well suited to analyzing the short-run effects of energy supply or price changes. It is more applicable to analyzing the impact several years into the future. Discussion suggested that projections five to ten years into the future would be most accurate as, by that time, energy price changes would have had time to induce changes in purchase patterns and these changes to have been incorporated, through replacement and modification, in the stock of energy using capital. Beyond this five to ten year interval, actual changes in the production structure and in consumer tastes may diminish the accuracy of the projections. The macro nature of the model limits its use to analysis of policy issues on a national scale as opposed to regional analysis. For example, national impacts of import changes and product use taxes can be handled by the model but the detailed regional impacts cannot.

Questions were raised concerning the accuracy of the estimation of the structural coefficients and the predictive accuracy of the results. The latter can be approached by simulations over the historical period with accuracy measured by mean square errors. Hudson has been involved in generating alternative simulations and analyzing the impacts on the economy and has not done mean square error analysis, but he acknowledged the value of such analysis and intends to perform these tests. One method suggested for testing the stability of the coefficients is by estimating them from partial samples.

An assumption of the model is that past behavioral relationships will continue to apply in the future, including reactions to price changes, the nature of new technology and changes in personal tastes. There was no suggestion for taking these factors into account. This seems to be a general problem common to all energy modeling and forecasting.

The possibility of using an aggregated input-output model incorporating price changes and endogenous coefficients to complement a more disaggregated fixed coefficient model was explored. Without adjusting the fixed coefficients in the latter model, the models would probably not generate consistent results. However, if the most sensitive coefficients or blocks of

coefficients in the fixed coefficient model were adjusted on the basis of results at the more aggregated level then the two models might be used together.

The problem of incorporating technical change, imports and the depletion of non-renewable resources was discussed. In the present model judgemental estimates of energy resource supply curves, which include imports of energy resources, are used; they are incorporated by altering technical change in the resource extraction sectors, which in turn alters energy resource price, until total U.S. demand for the resource equals available supply. Work on the model is underway to construct and incorporate explicit resource supply functions.

Many models, including the Hudson-Jorgenson model, are faced with the problem of forecasting prices. This model incorporates producer and consumer responses to changes in relative prices, but does not incorporate any real adjustments in production or consumption caused by inflation. However, inflation may affect real growth through its effect on cash flow and the investment process. As yet this problem has not been dealt with adequately in any model. To incorporate inflation, a monetary sector would have to be added to the model. This model would introduce cash flow variables and the manner in which they limit real adjustments such as new investment. In the discussion of the availability of finance for new investment two opposing views emerged. One is that institutions will adapt to provide new capital when the demand for it arises. The other is that this may not be so and that additional capital may not be available at all. A compromise, short of building an econometric model of the monetary sector, may be to introduce capital market conditions through the mix of relative prices in the producer behavior models.

DISCUSSION

McCALL: What happens to GNP?

HUDSON: GNP goes down by, if I recall it, by half a percent. You can substitute almost completely away from the energy production. Government spending doesn't change, so this tax relieves some other tax. We assume the revenue is fedback and the caveat here is that we are presupposing a long enough time interval for these adjustments to take place.

VERLEGER: That's real GNP that does down half a percent?

HUDSON: Real GNP goes down.

VERLEGER: Nominal GNP does not change.

GRIFFIN: Nominal probably goes up through the imposition of a tax.

VERLEGER: Ed, just one other question while we are on that table. Why don't those I-O coefficients you have in the model add to one?

HUDSON: Technical change. You don't have to put in one unit of input to get one unit of output. You put in less. They should add to about .92.

VERLEGER: They add to about .9487.

HUDSON: They should add to about .95. Inflation is about 1.2 percent per year.

GRIFFIN: Are you saying it increases the rate or it just increases the price index in the year 1985?

HUDSON: I'm just looking at one year. The level in that year is higher, so that means for that year the rate is going up. I'm not saying what time pattern that covers.

GRIFFIN: The prices will be one percent higher?

HUDSON: Right.

GRIFFIN: After full adjustment?

HUDSON: Right. And real GNP will be around half a percent low. On the table on pg. 86, some of the actual input-output coefficients are given. Energy input-output coefficients for all sectors go down, but they don't go down all that much. For manufacturing, it goes from .0235 with no tax down to .0231 with a tax. So this doesn't seem to represent any monumental shift in production patterns. But it is enough to free up a large amount of energy used. As we do down to the final block there, for manufacturing, the input-output coefficients for each fuel source are given; also, for capital, labor, energy, service, and materials, total energy input goes down, but, within that, coal goes down, petroleum goes down, gas does down and electricity goes up. Although electricity is now more expensive than it was, it becomes relatively cheaper compared to the other fuels. Total energy goes down and, in manufacturing, energy and capital are complementary, so you use less energy and less capital. Energy and materials are also complementary so you would use less material, and what takes their place are increases in labor services. So, what lets you get away with this economy in energy use in production is the shift towards more labor intensive

techniques.

KAUFMAN: I have a hard time visualizing that, in the sense of thinking about basic industries, there are high energy users that have major components of energy use. How can you become more labor intensive?

HUDSON: Well, you can make cement more labor intensive.

KAUFMAN: You might do it in the furniture industry.

HOFFMAN: You're substituting more labor intensive materials for aluminum, concrete, steel, and natural fiber instead of man made fibers. That's implicit in the model.

VERLEGER: I think that part of the substitution you capture in the model (we went through this this morning when Dave Wood was talking about the manufacturing sector) is due to the fact that you have not been able to disaggregate to the two digit industrial sector. If you go back to the literature on the estimation of aggregate production functions, especially the work of Fischer, you find that it could quite well be that some of the substitution is due to shifts in the mix of industrial output that you've been unable to isolate.

HUDSON: If you could shift away towards wood, for example, and away from aluminum, then you could still use as much energy in making aluminum as you did before, but your total energy input has gone down. This then briefly is the present state of our input-output model.

Let me try to recap by giving first what I think the potentialities of it are. It simultaneously, economy wide, picks up the links between raw energy and energy sectors. It systematically incorporates, I think, all the price effects, not only in terms of final demand, but in terms of production demand and the adjustments that are made in production to changes in price. What we have in mind to develop on this is incorporating some actual supply functions from Paul McAvoy to integrate raw material supply in the primary input into the natural gas sector. At the moment we just have to make some *ad hoc* assumptions about the average cost of producing each level of output and limits on the total output. We're incorporating flat and explicit supply function for crude oil. We are incorporating embodied technical progress so that the input patterns can change in response to the relevant price changes and also in response to preferential rate of technical progress. We can have electricity-saving technical progress in manufacturing, for example. We are working towards further disaggregation. Nine sectors is not a hell of a lot; it is about the smallest number you can get away with, I think. We're thinking of two digits, around 40 industries.

Now this extended disaggregation (I'm thinking now of the 300 sector models that are being talked about) is certainly desirable in terms of working out these allocations that have a whole lot of disaggregation. It depends critically on what you want to use the model for. It seems to me that, when you're working out to the 1980's and 1990's, what you gain by disaggregation is at a very severe loss in building a lot of rigidity into the model. The more detailed you get, the less confidence, I think, you have in presuming these relationships will hold constant for the next 25 – 30 years. So at some point, you've got to trade off detail, which lets you get down to some of these specific prices, instead of going on with the cost of this behavioral constancy.

What sort of uses might be made of this model? We have run it out to see total energy requirements which gives a nice looking output. I think that it is useful in doing this in a way that incorporates prices and in a way that incorporates all sorts of feedback effects. Also the fact that it is an equilibrium model does mean that you limit its use away from an equilibrium, for example, in determining what's going to happen next year. But it is more useful, I think, for what's going to happen in 1980. The macro nature of it, I think, limits it to generating scenarios into which the people operating main power supply for San Francisco can plug in for national developments regarding fuel prices and possibly relevant availabilities of different fuels. And the use we have been making of it is the analysis of different tax programs (BTU tax, sales tax, tax on imports, tax on specific uses of products) and then following through in terms of impact on prices and the impact of prices on the various types of consumption.

KAUFMAN: I have a question about two kinds of accuracy. One has to do with the accuracy of structural estimation coefficients and the other is the testing of predictive accuracy of the model. Could you say something?

HUDSON: The accuracy rests on the price possibility frontier which was fitted to 1947-1971 data. Consider the energy sectors, for example, there has been a lot of relative movement in energy prices and in shares of energy use. The movement was a decline in real prices of energy, particularly of electricity. There was an overall change in the real and the relative price of energy, and, within energy, a quite substantial movement of relative price of different fuels. It was presumably caused by changes of fuel input shares and energy input shares. So we do have quite a reasonable range of semi-orthogonal observations. But is the 1947 to 1971 pattern going to continue to apply in the future? The reasons why it wouldn't would be of two sorts. One is

the energy specific change in technical progress. Who knows what's going to happen there. I think we can answer criticisms along that line when we get to the point of having incorporated technology transfer for each input share. At the moment we can't.

KAUFMAN: I was thinking, in a more methodological sense, of predictive accuracy in a mean squared error sense, if you fitted and then came back to see the restrospective prediction. What are the usual kinds of estimates of accuracy, confidence intervals, this kind of thing, one can make about structural coefficients in a model like this?

HUDSON: Well, this gets back to what we were talking about this morning. My feeling is to put weight on the mean square type of error thing rather than on confidence intervals for specific parameters. The reasons are: first, you go up to linearity; second, you are churning this whole system through matrix inversion, so I wouldn't care to work out confidence intervals at the other end; third, when you put the whole system together and simulate it, I think the accuracy of each parameter is not so relevant, perhaps, as doing the simulations and finding what comes out at the other end.

Okay. That establishes that we should have done it. Frankly, we haven't done it yet. It is on the program to do. I've been more concerned with finding out what will happen in the year 2000. I think we should do it.

GRIFFIN: Have you done any tests of stability of coefficients by estimating over a restricted sample?

HUDSON: No, that's not on the program.

EATON: If you were going to be ruthless with your own model, what would you say would be the major reasons why it shouldn't be used.

HUDSON: It should not?

EATON: Why it should not be used by policy analysts for policy decisions.

HUDSON: Well, firstly, I would say it is very highly aggregated, which is a cost in some uses, though certainly not all. Secondly, I would say, the other main thing is whether or not past behavioral patterns can be expected to continue in the future in two senses: 1) in the technology sense, such as what inputs you need and what input mix for what outputs and 2) personal taste. If people want to drive around on Hondas and get 100 miles per gallon, we can't take that into account, but when you're forecasting up to 2000, that is quite a serious qualification.

HOFFMAN: You did make some comments about your feeling of near term accuracy, but the 1980 or 85 is probably good. Could you make some estimation of longer term projections? What are your subjective estimates of accuracy after the year 2000 as compared to the 1980-85 forecast? The problems become more severe as you go out past the 5 to 10 year time horizon. How badly does it deteriorate out there?

HUDSON: I have no way of knowing how much it deteriorates. You see, there's sort of a cutoff point in short-run and long-run when it's admisable to use this type of methodology and when it's too soon to use it. It is probably limited by the time it takes to turn over energy using capital stock, although it's been demonstrated that even the use of capital stock in the last year showed tremendous possibility for substitutions. I don't know, just how to put a figure on it. In somewhere between five and ten years you should see the entire automobile stock getting turned over and most of the production equipment increased. The thing that wouldn't turn over is structures, but you can insulate them well within that time, and you can replace such things as space heating units.

HOFFMAN: I think it's true that the automobile population can be turned over by 1980, say 8 to 12 years time period. In looking at the introduction of technologies I think that, if you are not changing in the energy supply mix, probably the appropriate view to take is that that is roughly a ten year turnover period. If you look at something like the introduction of electric cars, where you're implying a new load structure for electric utilities, you're tied more basically to changing supply mix which has a much longer lifetime and more inertia. You get some variability in the turnover of appliances depending on how tightly they are tied into the existing supply system or whether you are looking for a shift in the supply system.

EATON: You mentioned several limitations of the field. Would you describe how serious these limitations are to the utility of your model for the year 1980? In what particular aspects of policy do you feel it would have the greatest limitation?

HUDSON: Anything involving a lot of detail on regional demand or on the sectoral use of energy couldn't be handled by this alone. It may be limited in the type of policy question you can ask it even on the macro level. If you put on a tax, it will come out saying this much energy could be saved, and this will be the effect on employment, and then this will be the effect on capital requirements. You might criticize it by saying that it is just looking at past relationships between capital requirements and change in production, where, in fact, it should

be looking at new technical capital requirements. It can't tell you the effect on specific production techniques or on specific income groups and households. It can't tell you, for example, how you should approach a sudden cut in oil like we had last year.

EATON: If there is a major dislocation in some part of the system or price or personal aspirations, you're saying you have to redo the model?

HUDSON: For something very specific, such as a short-run disruption analysis, it's not the best model to use. It couldn't handle, as it now stands, a very specific thing like a sudden oil embargo or aluminum embargo. That doesn't mean it couldn't be adapted to handle that sort of thing.

EATON: Can it be adapted to a long-term dislocation of lifestyles or a major shift in prices, or would it have to be reformulated?

HUDSON: It gives you a framework for inserting what you think might be long term changes in lifestyles on patterns of consumer demand, on housing, and this sort of thing. You have to translate what you think is going to happen into actual demand requirements. It is surely open to criticism on that point. I do not know of any model that isn't.

BENENSON: Ed, what do you think about the idea of using your model, which incorporates price changes, as a control on a more disaggregated model that can't incorporate price changes? Look at this disaggregated picture, and as long as it checks with the aggregate picture which has incorporated price, then you are all right. If it doesn't, then you go back and adjust so that you get a consistency between models. Is that feasible?

HUDSON: Well, what would happen in a fixed coefficient input-output model if you imposed an oil embargo? Wouldn't you get a proportional cut back in all production, unless you allocated in an *ad hoc* manner oil availability? So unless you were prepared to supplement a fixed coefficient input-output model with your own imposed adjustment, I'm not sure that the two would ever converge.

BENENSON: Or unless you incorporate inter-fuel substitution.

HUDSON: That sort of thing would work.

HOFFMAN: One problem is that you've got other coefficients that you want to modify in response to price changes. Maybe you don't have to deal with all of the 365 coefficients. Maybe you can pick out a couple of dozen that are most sensitive.

BAUGHMAN: I have a couple of questions having to do with the construction of the supply and demand balances. I think they get into some of the methodological issues. First of all, the imports, specifically the petroleum imports, are introduced exogenously?

HUDSON: Yes.

BAUGHMAN: The other thing is, you indicate that there's a place in here where you can put in technical change. Yesterday we were discussing how nuclear and coal gasification came in. Now, this requires a change of the whole technical vector if you're going to adopt more nuclear into the electric utility system. What has that done in the construction of some cases, how was it done exogenously if it was done, and how did you accomplish those particular changes to come up with the supply demand balances that you have?

HUDSON: As it presently stands, you put in a technology vector within each production activity. We are restructuring the model for bringing in coal gasification to be treated as a separate production activity with exogenously specified coefficients regarding all input capital, input labor, and so on.

BAUGHMAN: Okay. I guess the thing that confuses me then is that in most cases we're talking about the depletion of nonrenewable resources. Depending on what you put in for exogenous trends, for example, imports or coal extraction, and so forth, the supply function in year 2000 looks a lot different depending on what happens between now and the year 2000. I don't see how that change could take place in the model as you go through a simulation.

HUDSON: That's a fair point.

BAUGHMAN: How can you place any confidence in these prices? Are these just extrapolations of . . . ?

HUDSON: What we have done for the fuel extraction activity amounts to judgmental supply curves, so that to solve the model, the thing that does the work is the productivity curve—how much input you've got to put into gas extraction to get one unit of output.

BAUGHMAN: These are endogenous?

HUDSON: But the change for effect they endogenize so that they bring the average cost of each thousand cubic feet of gas . . . The cost which comes out of the model, as a function of this productivity reconciles supply and demand.

BAUGHMAN: It is the coefficients which are changed exogenously and those determine the prices?

HUDSON: Yes, and then the check is made. This demand, which is predicted by the inter industry structure, and supply, which is predicted at that price by this judgmental supply curve should match; if they don't, we change productivity and resolve it.

BAUGHMAN: So, essentially, the, these projections that you show are just judgmental forecasts on the spot.

HUDSON: It doesn't include any explicit inflation effects. For example, at seven dollars a barrel for oil, the US will be able to produce 13 million barrels a day in 1980.

VERLEGER: It seems to me that this model and all models are faced with one problem, the test of price forecasting. The problem that people haven't worried about adequately yet is the effect of this rapid inflation rate on the cash flow problems to be coped with and tracing that back to the price for electricity. This isn't just a criticism of the Jorgenson model. I guess, Marty, the work you're doing indicates that there's a debt rollover problem and financing problem that is just completely absent from all this real analysis, and yet it's going to be a major problem over the next five to ten years. The track of the energy economy is dependent on the path we take over the next five to eight years, which will in turn affect the results in 1990 to 2000. Specifically what I'm thinking about is the Brimmer speech where you do an examination of how many bond issues 8 billion dollars worth of bonds that have to be rolled over, that were issued at three percent interest rates, 13 and 18 years ago, that are going at a much higher interest rate, plus you get the cash flow problem and higher labor cost.

HUDSON: Yes. That's very true. To get around that you'd have to combine a monetary sector with a complete fuel and non-fuel production.

VERLEGER: And this would also extend to the demand sector where you have this set of consistent demand options which cannot really recognize the fact that the consumer gets locked into a certain set of expenditures, like mortgages, that are basically fixed for a significant time horizon. The critical problem is the effect of inflation on these models.

HUDSON: I guess the question has to be, does inflation affect different real variables differentially?

VERLEGER: I think partially you're trying to capture it, but the problem with input-output models has always been that they don't really capture inflation. By making the input-output coefficients a function of relative prices, you have partially captured it. But, basically, you can't capture the problem of the embedded capital cost and embedded life cost as you shift from one rate of inflation to another rate.

HUDSON: So, in effect what you're saying is this is an equilibrium type of model. It doesn't capture transition effects caused either by monetary factors or shortages of imports.

BAUGHMAN: It's not even clear that it gets to the steady state along the same line. You've got a set of prices that come out of this model after you introduce exogenous coefficients of supply. It seems to me that depending upon the policy that one adopts that there's a whole capital allocation problem (you have investment in the final demand vector) and there's a question of how that gets allocated among the intermediate industry sectors. That depends on the price and on the capital output ratio and so forth, and there's really no connection between those two.

HUDSON: At the moment there is not. That would be a criticism of the model as it stands at this point. It is on our program to dynamize the thing and have investment capital feedback over the time and also link the final investment vector with capital requirements for each of the producing sectors. That's something that should be done.

BAUGHMAN: How important is that in the forecast that you're making for 1985 to 2000?

HUDSON: It would only be important, I think, if the sectors grew at very different rates and if the capital requirements for each sector differed quite substantially. In fact the sectoral rates of growth don't differ all that much at this level of aggregation. Some may be growing at 2-1/2 percent and some at 4 percent.

BAUGHMAN: You don't have this feedback effect in there though, right?

HUDSON: Well, I'm not sure it is.

KAUFMAN: There are some segments of the present capital markets that are going to change dramatically in structure. For example, talking about a Trans Alaska Pipeline, one is presently talking about capital requirement of 10 billion dollars. There's no extant capital market in the United States that is presently structured to be able to handle effectively a single investment project of this order of magnitude. The only way that it is going to be done is by creating new types of institutional structures that probably are going to involve government to a substantial degree. The issue here is, if you forecast

the scenario like that, what do you do in a model like this to adapt the response to structural changes that are institutional features of this type?

HUDSON: Well, even if the government were to completely finance this, it would have a large effect on financial ways and money flow. Would it necessarily have any effect on real flows?

KAUFMAN: The rates aren't really being determined in the same fashion as the rates that you are examining in a context of our present environment. No, there's some kind of change going on there. I don't know. What's your feeling about it?

HUDSON: My feeling is that there are so many things which could affect this global sort of picture. To build them would result in such complexity and rigidity of the model that I'm not sure the main effect would be a plus when you're operating ten, fifteen years away.

KAUFMAN: Where are you coming out? I want to make sure you're saying essentially that you want to assume, as a matter of conservatism in predicting the structure of the future, that the present kind of capital market is still going to be there and that you'll operate within the context of the institutional features of those markets.

HUDSON: No, I'm not saying that. I guess it boils down to my saying that capital markets will evolve to be consistent with the forecast (real developments) without constraining those real developments.

VERLEGER: I didn't mean to imply criticism of this particular work. It's a problem that seems to be a general one with all energy models. We're concerned with real growth in a sector and you're looking at the real elements, and there is a tendency to ignore the existence of financial markets, the structure of the financial markets, and the structure of inflation. Yet, we know right now there is a large flow of cash into the Middle Eastern countries and that these countries are going to handle that cash quite possibly in a different way than the developed countries would have handled it. They may prefer a different mixture of instruments, such as short vs. long term and this could boost the rate of interest, possibly slow the rate of investment, or just generally affect a) the growth of the real economy and thus b) trace down into these energy sectors. I agree with you that it is possible to embed it into a model, but one also has to begin to worry and impose that kind of a thing possibly exogenously.

KAUFMAN: Well, there are two opposing theses. One is that if the need is there, some institutional feature will come up to handle it. But if you talk to the people out there in the real world operating their own company, they ask where is the 10 billion dollars going to come from? We don't see where we're going to go out and grab it, and that feeling is prevalent at least among people that I've heard in industry.

HUDSON: I could say the federal surplus the next two years from now may be 10 billion dollars, and there is your financing in one shot.

VERLEGER: What it does is to change the rate of relative prices, interest rates go up, and some projects will be canceled because of prices. This mix of relative prices that one is looking at has to be adjusted for capital markets.

HUDSON: You may be able to go halfway by putting in, through a capital price, what the interest rate does to the price of capital services rising faster than other prices.

KAUFMAN: It sounds like a sensible compromise.

HOFFMAN: In your projected cost in Table 12, to convert the cost of electricity to allow for the fuel cost and to look at the implied reduction of other costs, it turns out that the other costs making up the cost of electricity by the year 2000 have to be reduced by the factor of 2 to get from two cents/kwh down to 1.71. I was wondering if Dick, as a representative of the utilities, can conceive or construct any technological scenario that might get you such a reduction.

BREEN: No, I can't as a matter of fact.

HOFFMAN: You looked at nuclear power parks . . .

BREEN: I can't do that. As a matter of fact, I wanted to pose a question in regards to the rather optimistic scenario or base projection where nuclear plants are brought on line at a pretty fast rate. In addition, the share of electric energy production for nuclear plants increases during this time. It seems to me to be quite a bit more optimistic than what the industry feels. For example, in California I don't see how it's particularly feasible. Then, or on top of this, the result in your base projection of almost a three quarter percent real average price decrease in electricity over this period of time would bother some of the sensitive minds of people in the industry.

HUDSON: You're asking the same question Ken asked. What gives us the result is the assumption we make about trends in productivity in the electricity sector. Historically, the productivity in an economic sense, not fuel conversion, has been more than rapid enough to halve

the unit cost in the post war period. So that if that rate of technical progress continued, non fuel cost per unit of electricity output would at least halve. It may be that our assumption about what is possible is too optimistic. We build in a reduction for past trends, but still we should know that the productivity was faster than nuclear.

Through 1985, we say, well, we're locked into the present, existing, under construction capacity. So, of course, we know the nuclear imput, and we'll allocate the rest to fossil fuels on the basis of cost. So that's just the figure through 1985. Through the year 2000, we, in effect, did the reverse and allocated fossil fuels on the basis of cost and required the rest to be made up by nuclear input. The trouble is, in modeling nuclear in an economic framework, we have no past experience to go on to predict the cost of nuclear and predict the trade-offs between nuclear and fossil fuel.

BREEN: I'll try to bring this back from modeling abstractions to the real world. We have additional constraints which are political and institutional, and perhaps it's worthwhile looking at alternate projections with regard to scheduling any kind of technology on line and trying to justify it.

HUDSON: I share your concern. Will the people be willing to put up with nuclear reactors from a safety point of view? We are faced with the situation where, all of a sudden, you don't have something. People have the habit of saying, well, if its dirty or unsafe, we won't put up with it, but if they're faced with it they may change. I'm not saying that this is likely, but I am saying that I would be very hesitant to impose that sort of constraint in predicting 15, 20 years from now.

BREEN: But you see I've become a little worried. It takes 10 to 12 years on an average to bring a nuclear power plant on line. This means that today we can make plans only beyond 1985 and not before that.

HUDSON: With this sort of aggregate modeling, for that year we'll just have to take existing plants as possible and . . .

BREEN: I only throw that out because I'm supposed to speak from a users' point of view. I have to try to bring this into context with how we would be using this model. I appreciate our different intended uses to begin with.

BAUGHMAN: You indicated that there were some data problems in getting this thing constructed; if you were to go back and construct at the same level as it is now, what would you put down as the first five elements in your wish list for data that you don't have now, but would like to have?

HUDSON: I guess the critical gap is the fuel flows—trying to get figures on how much each sector purchases, what fuel and at what price.

BAUGHMAN: How did you get those for the inter-industry table?

HUDSON: There are four industry tables published. Now to fill in, there's a lot of physical flow data that can be converted reasonably into constant dollar flows. Then assumptions, sometimes reasonable and sometimes not, have got to be made about the prices.

VERLEGER: If you actually go through the Fawcett document that is part of the Ford Foundation publication, they did break it down by types of petroleum products. There are fairly good data for the disaggregation that we're talking about to get the real flows by petroleum products, by coal and by nuclear power. The critical problem came in getting adequate price data on specific petroleum product flows.

0 0 0 4 3 0 0 8 9 4

METHODOLOGICAL ISSUES IN THE ECONOMETRIC ESTIMATION OF ENERGY DEMAND ELASTICITIES

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SUMMARY

Griffin's paper describes preliminary work on a model to estimate the long-run price, cross-price, and income elasticities of energy sources using econometric analysis on pooled international data. In recognizing the derived demand nature for crude oil and the numerous possibilities for long-run interfuel substitution, Griffin proposes determining the aggregate final demand for energy in each of eight fuel-using sectors. In a second step, the shares of the respective fuels would be determined. The first step emphasizes the roles of economic activity and energy prices relative to other input prices as key determinants of aggregate use in that sector. In the fuel share equations, relative fuel prices are the primary determinants of fuel shares thereby capturing the interfuel substitution effects. Since there are typically 3 or 4 fuels consumed in each sector, a system of 30 to 35 behavioral equations is forseen.

The sample consists of observations for 20 OECD countries drawn at 5 year intervals from 1955-70, giving 80 observations. The primary advantage to using international data is that wide variations in relative fuel costs are observed due to tariff and excise tax differences. This provides a sample over which long-run adjustments may be estimated. The use of international data does, however, introduce bias due to insufficient price data and international differences in tastes, technology, and optimization. These are not trivial problems. For example, regulation in the electric utility sector may result in non-cost minimization behavior.

The paper discusses two alternative procedures for estimations of the fuel shares. The first is use of ordinary least squares. An alternative approach contemplated, is the Translog cost function approach popularized by Christenson, Jorgenson and Lau. The advantages and drawbacks of each are discussed but a final assessment must await the actual results of the two models. The basic issues are whether the restrictive theoretical conditions of the Translog approach are met statistically and how large the loss in goodness-of-fit will be with the Translog model.

The applications of the model are envisioned to be for long-run forecasting and policy analysis. Since the "long-run" is not defined in the model, the user must attach a time period sufficiently long to allow the stock of energy consuming capital to be replaced or redesigned. In many sectors, this may be 15 to 20 years. The approach is more likely to yield insights for a group of countries than for any one in particular, since omitted intercountry differences may average out.

* * *

I. INTRODUCTION

It is apparent from the perspective of this year that the oil embargo and the resulting dramatic increases in crude oil prices were a tremendous economic success for OPEC. Despite the multiple increase in price, the producing countries find themselves still facing markets with highly price inelastic demand functions. Whether or not these actions will yield optimal profits in a present discounted value calculation depends to a large extent on the magnitude of dynamic supply and demand elasticities. This paper is concerned with estimating these dynamic demand responses utilizing international data.

To meaningfully discuss the price elasticity of crude oil demand, it is necessary to attach a time subscript in recognition of its essential dynamic nature. In the short-run of a year or less, petroleum demand depends essentially both on the stock of petroleum consuming equipment and its rate of utilization. Given the short-run fixity of the capital stocks, price effects work only through the utilization rate of that petroleum consuming stock. It is not surprising to find highly inelastic demand elasticities over such periods. As the time frame is lengthened, additional energy saving responses become economic. Over a two to seven year period following a major price increase, minor energy-saving process modifications, which will be called within-process adaptations,[1] become technically and economically feasible, even

though the composition of energy consuming processes are not likely to change appreciably. Thus over this time frame, price responses can take the form of both lower utilization rates of consuming equipment and improved energy efficiency through within-process adaptations.

As one extends the time frame of the price response and allows the time subscript on the particular price elasticity to reach ten years, still a third type of price response becomes quantitatively significant. "Between process" changes, allowing even greater substitution of other inputs for petroleum, become possible as large parts of the stock of energy consuming equipment begin to turn over. For example, this type of between process change may be the substitution of nuclear power generators for oil-fired units. Moreover, these long-run substitution possibilities are likely to continue for several more decades as the complete composition of energy consuming processes are replaced. In the case of insulation and construction of homes, the conomist's "long-run" can extend to that period that Keynes characterized so aptly.

The estimation of dynamic price elasticities with particular emphasis on these within and between process adjustments poses a particularly difficult problem because of the long time period involved. Time series econometric analysis is limited in several respects. First, the lack of significant variation in the independent variables proves a serious impediment especially in delineating longer period responses. Second, given the long time period of perhaps fifteen to twenty-five years for which lagged observations are needed, time series samples tend to be small, therby compounding the first problem. Some distributed lag formulations such as the Koyck or more general, rational distributed lags have properties which alleviate the degrees of freedom problems, but have adverse side effects.[2] For example, the Koyck distributed lag forces a common geometrically declining lag structure on the dynamic price impacts. From the previous discussion, there would appear to be little a priori basis for such an assumption. While the rational distributed lag places negligible restrictions on the various dynamic price effects, its ability to characterize phenomena over the long periods proposed here seems highly questionable.[3]

In view of the deficiencies of time series analysis to elicit a dynamic price elasticity extending over twenty years, an alternative approach—the use of cross-sectional data across nations has sufficient robustness since tariff differentials have created substantial inter-country price differences. Moreover, these tariff differentials have been in effect since the post-war period so that observed price differentials represent those common to a much longer period. Presumably the coefficient relating price and consumption represents a long-term price response after most between-process adaptations have occurred. Unfortunately, one is not able to characterize exactly the time subscript for the estimated price elasticity except to state that it includes the long-run between-process adjustments. As discussed subsequently, the introduction of a time series sample component at five year intervals in addition to the cross-section helps to define the period of time required for long-run adjustment.

II. SPECIFICATION AND ESTIMATION

Economic Considerations:

In estimating a long-run price elasticity for crude oil, two key factors must be recognized. First, the demand for crude oil is a derived demand based on a technological relationship between crude oil and petroleum products. Even the demand for petroleum products can be viewed as a derived demand for a set of services. For example, the demand for gasoline, like the demand for diesel fuel oil for train fuel, is a derived demand emanating from the demand for transportation services. In turn, the demand for crude oil depends on the demand for petroleum products. Therefore, first the demand for the respective petroleum products should be determined and then proceed to determine the price elasticity of crude oil.

A second key element is characterizing the various fuels' substitution possibilities which exist both among petroleum products and with non-petroleum energy sources. The extent of substitution among energy forms varies significantly depending on the sector under consideration. For example, as a fuel for railroads, coal, diesel fuel and heavy oil are potentially competitive fuels given the existing variations in their relative prices. Yet, for power generation purposes in the same country, diesel fuel oil offers no effective competition to heavy fuel oil or coal due primarily to differences between rail transport and electricity generation technology. Obviously then, there is a need to define both "the product" and "the market" in which it is to be sold in an economically and technologically meaningful context. In response to these considerations, we consider the demands for eight different energy sources (coal, gas, electricity, gasoline, heavy fuel oil, light fuel oil, kerosene, and miscellaneous petroleum products) in the following seven markets: electricity generation, other energy transformation activities, automotive transportation, non-automotive transportation, iron and steel industry, other industries, and residential (including agriculture, etc). Admittedly, disaggregations to even these seven markets are indeed broader than desired, nevertheless, they are the most detailed available.

Essentially a two step estimation approach is proposed. In the first step aggregate energy demand in a particular market is hypothesized to depend on economic activity and the relative price of energy to other commodities. After determining the aggregate demand for energy in a given market, two alternative sets of estimated equations are estimated to determine the market share of any particular fuel. This partitioning of the problem—by determining aggregate energy demand and then the specific fuel shares—follows implicitly from the assumption of a group-wise additive price possibility frontier for each sector which is both homothetic and separable in the energy commodities within the energy aggregate.[4]

Determination of Aggregate Energy Demand:

In the derivation of aggregate energy demand equations, economic theory serves as only a general guide to the proposed specification. First, we proceed by recognizing that the demand for the output (X_i) of any given sector i depends on aggregate demand, measured by real GNP (X), and on the price of section i's output (PX_i), relative to the price of other goods, measured by the GNP deflator (P).

$$X_i = f(X, \frac{Px_i}{P}) \qquad (1)$$

In turn derived demand for energy (E_i) into sector i depends on the output of the sector (X_i) and on the prices of energy (Pe_i) and other inputs (Po_i).

$$E_i = g(X_i, Pe_i, Po_i) \qquad (2)$$

After combining equations (1) and (2), the demand for energy inputs sector i is seen to depend on aggregate demand and a set of relative prices as follows:

$$E_i = h(X, Pe_i, P, Px_i, Po_i). \qquad (3)$$

Price data for Pe_i and Po_i were not available for the variety of sectors under consideration; however, this is not likely to be serious since the price of other factor inputs, Po_i, and the sector price Px_i, are probably close surrogates for each other in view of the low energy cost component of most goods. In addition, the GNP deflator, P, serves as a good proxy for these other costs, so we simplify (3) as follows:

$$E_i = \phi(X, \frac{Pe_i}{P}) \qquad (4)$$

Written in estimation form, we posit a simple log-linear functional form.

$$\ln E_{ijt} = a_0 + a_1 \ln X_{jt} + a_2 \ln \frac{Pe_{ijt}}{P_{jt}} + e_{ijt}$$

i=1...n markets
j=1...m countries
t=55, 60, 65, 69 (5)

This particular functional form assumes a constant income elasticity (a_1) across all countries, although the validity of this assumption is tested subsequently by analysis of covariance tests. The coefficient a_2, likewise assumes a constant energy price elasticity of demand. Ordinary least squares (OLS) is proposed to estimate the coefficients in (5).

By estimating separate sectoral energy demand equations, we are able to identify much more closely the impacts of economic growth and price. Both income and price elasticities are expected to differ markedly among sectors. For example, the tendency for economic growth to raise the share of manufacturing output to GNP implies an income elasticity greater than one for energy demand from other industries. The substitution between energy and other inputs may tend to be much more limited in iron and steel manufacturing, where chemical reactions involving fuel inputs in addition to process heat are important, than in other industries where both capital/energy substitution and energy/labor substitution are possible.

Determination of Fuel Shares in a Simple Framework:

As noted earlier, the assumptions of separability and homotheticity allows the shares of fuel inputs to be determined solely on the basis of relative fuel prices. Separability holds if the ratio of budget shares of any two fuels within the aggregate is independent of the prices outside the energy aggregate. Homotheticity holds if the budget shares of fuels are independent of total expenditures on the energy aggregate.[5] The particular formulation chosen here does not follow from a particular hypothesized cost function; however, certain theoretical conditions provide a guide in the specification of the relationships. We begin by invoking the condition of linear homogeneity in prices in the specification of the functional form. The market share (MS_{ki}) of fuel k(f_{ki}) in market i depends on the relative prices of all fuels (Pf_k) relative to the lowest priced fuel P_{min} as follows:[6]

$$MS_{ki} \equiv \frac{f_{ik}}{E_i} = f(\frac{Pf_1}{P_{min}}, \frac{Pf_2}{P_{min}} \ldots \frac{Pf_s}{P_{min}}) \quad \begin{array}{l} k=1...s \text{ fuels} \\ i=1...n \text{ markets} \end{array}$$

where (6)

$P_{min} = \min [Pf_1, Pf_2 ..... Pf_s]$ and all prices are given in dollars per efficiency-adjusted btu's.

More specifically, the estimation form is

$$MS_{i1}=a_{10}+a_{11}\ln\frac{Pf_1}{P_{min}}+a_{12}\ln\frac{Pf_2}{P_{min}}\ \ldots\ +a_{1s}\ln\frac{Pf_s}{P_{min}}+e_1$$

$$\vdots$$

$$MS_{is}=a_{so}+a_{s1}\ln\frac{Pf_1}{P_{min}}+\ldots\ldots\ldots\ldots+a_{ss}\ln\frac{Pf_s}{P_{min}}+e_s$$

$$i=1\ldots n \text{ markets} \qquad (7)$$

Clearly, this specification exhibits linear homogeneity in prices such that a doubling of all prices has no effect on market shares.

In addition, by invoking the accounting identity that the market shares sum to 1, we obtain additional restrictions on parameter estimates. For example,

$$\sum_{k=1}^{s}\frac{\partial MS_k}{\partial\left(\frac{Pf_{s'}}{P_{min}}\right)}=\sum_{k=1}^{s}a_{ks}\frac{P_{min}}{Pf_{s'}}=0$$

or

$$\sum_{k=1}^{s}a_{ks'}=0 \text{ for } s'=1\ldots s \text{ fuel inputs.} \qquad (8)$$

From the condition in (8) and the fact that market shares sum to one, it also follows that

$$\sum_{k=1}^{s}a_{k0}=1. \qquad (9)$$

Theoretical restrictions on the coefficient signs are not really operative in this case since one is explaining the share of fuels demanded. The standard result that the own price elasticity must be negative suggests that the coefficients a_{kk} (k = 1 ....S) are negative only if total energy purchases (E_i) are held constant. It is conceivable that a price reduction in a major fuel would result in a greater percentage increase in total energy demand (E_i) than for the specific fuel (Pf_s) which was lowered in price. Nevertheless, one would expect non-positive coefficients for the own price coefficients. For cross price effects one must rely primarily on a priori evidence to suggest which fuels tend to be complements and substitutes.

To recapitulate, we have a system of s equations with s(s+1) unknowns with s + 1 linear restrictions. Ordinary least squares estimators will produce a set of estimators meeting the above restrictions.[7] The OLS estimators will be best linear unbiased estimators providing only $E(e_s, Pf_s/P_{min}) = 0$ and $E(e_{st}e_{st'}) = (t'\neq t)$. The stronger condition that $E(e_{st}e_{s't}) = 0$ $(s \neq s')$ does not hold in this case causing one to conclude that generalized least squares estimation is necessary for efficient estimators. As shown by Dhrymes, however, this is not necessary since the set of independent variables are identical in all equations of the system.[8] Aitken estimation would result in no efficiency gains.

The advantages of this particular model are several. First, the estimation approach relies on the standard ordinary least squares estimation approach, providing a simple method which avoids simultaneous estimation of a number of equations. Second, the specification chosen imposes only very weak restrictions on the functional form (linear homogeneity, and the market share identities). In the next section, we consider an alternative functional form which provides a much closer link to economic theory but lacks the simplicity of the above approach.

Determination of Fuel Shares With a More Elegant Model:

Christensen, Jorgenson, and Lau's development and exposition of the transcendental logarithmic production frontiers has opened wide opportunities for the modeling of energy inputs within a well-defined theoretical framework.[9] They provide functions which are local second-order approximation to any production frontier and implicitly begin by invoking only profit maximization and constant returns to scale. The importance of this work is that tests of the theory of production and additivity are possible and not merely assumed a priori. This approach has already been applied extensively to time series data by introducing energy as a argument in these functions.[10] In view of its general equilibrium theoretical basis, a cross-sectional framework seems to be a next step.

Following the work of Berndt and Wood, we focus on the trans log cost function because it places no a priori restrictions on Allen partial elasticities of substitution and approximates an arbitrary twice-differentiable cost function. In particular, we assume a cost function which is separable and homothetic in the inputs within each aggregate such as capital (K), labor (L), energy (E), and materials (M).

$$C = f(Q, P_K, P_L, P_E, P_M) \qquad (10)$$

If energy enters in a group-wise additive manner, we may postulate the following translog cost function governing the inputs of specific fuel types:[11]

$$\ln C_1 = \ln a_0 + \ln Q + a_1 \ln Pf_1 + a_2 \ln Pf_2$$
$$+ a_3 \ln Pf_3 + \ln Pf_1(\tfrac{1}{2}a_{11}\ln Pf_1 + a_{12}\ln Pf_2 + a_{13}\ln Pf_3)$$
$$+ \ln Pf_2(\tfrac{1}{2}a_{22}\ln Pf_2 + a_{23}\ln Pf_3) + \tfrac{1}{2}a_{33}(\ln Pf_3)^2 \qquad (11)$$

where

$$C_1 = P_1f_1 + P_2f_2 + P_3f_3 .$$

As in the simple share model above, linear homogeneity in prices arising from cost minimization results in the following "equality" restrictions:

$$\begin{aligned} a_1 + a_2 + a_3 &= 1 \\ a_{11} + a_{12} + a_{13} &= 0 \\ a_{12} + a_{22} + a_{23} &= 0 \\ a_{13} + a_{23} + a_{33} &= 0 \end{aligned} \qquad (12)$$

Given output and fuel prices, we derive the cost-minimizing input demand functions as follows:

$$\frac{\partial \ln C_1}{\partial \ln Pf_i} \quad \frac{\partial C_1}{\partial Pf_i} \frac{Pf_i}{C_1} = a_i + \sum_{j=1}^{3} a_{ij} \; i, i=1...3 \qquad (13)$$

Since

$$\frac{\partial C_1}{\partial P_i} = f_i \qquad i=1...3$$

it follows that the cost shares can be expressed as

$$M_1 = \frac{Pf_1 \cdot f_1}{C_1} = a_1 + a_{11} \ln Pf_1 + a_{12} \ln Pf_2 + a_{13} \ln Pf_3 \qquad (14a)$$

$$M_2 = \frac{Pf_2 \cdot f_2}{C_1} = a_2 + a_{12} \ln Pf_1 + a_{22} \ln Pf_2 a_{23} \ln Pf_3 \qquad (14b)$$

$$M_3 = \frac{Pf_3 \cdot f_3}{C_1} = a_3 + a_{13} \ln Pf_1 + a_{23} \ln Pf_2 + a_{33} \ln Pf_3 \qquad (14c)$$

In addition for the cost function to be well-behaved, it must be concave in input prices and yield positive demands. The latter can be tested simply by examining predicted demands over the sample period. The former depends on the negative semi-definitiness of the cost function's Hessian matrix.[12]

From the coefficients in equation (14) it is a straightforward procedure to calculate the elasticities of fuel substitution and price and cross price elasticities. Uzawa shows that the Allen partial elasticities of substitution between fuels i and j are[13]

$$\sigma_{ij} = \frac{C_1 \dfrac{\partial^2 C_1}{\partial Pf_i \, \partial Pf_j}}{\dfrac{\partial C_1}{\partial Pf_i} \dfrac{\partial C_1}{\partial Pf_j}} \qquad (15)$$

which as Berndt and Wood[14] indicate, can be rewritten as

$$\sigma_{ii} = \frac{\sigma_{ii} + M_i^2 - M_i}{M_i^2} \qquad i=1...3$$

$$\sigma_{ij} = \frac{a_{ij} + M_i M_j}{M_i M_j} \qquad ij=1...3 \qquad (16)$$

Allen shows that the cross price elasticity of demand (n_{ij}) is related to the elasticities of substitution as follows:[15]

$$n_{ij} = M_j \, \sigma_{ij} \qquad (17)$$

Stochastic error terms (e) with the standard properties ($E(ee') = \sigma^2 I$ and $E(e, Pf - = 0)$ are assumed. It might appear that ordinary least squares can be applied in a manner similar to the previous share equations with one of the three share equations omitted to fulfill the restrictions in (12). However, this estimation approach would not meet the additional symmetry constraints that coefficient a_{12} in equation (14a) equals coefficient a_{12} in (14b). Symmetry constraints also become implicit in (12). In addition inequality constraints implying concavity may need to be imposed, further illustrating the intractability of ordinary least squares. Following Christensen, Jorgenson, and Lau, we utilize the minimum distance estimator for non-linear simultaneous equations discussed in Malinvaud.[16]

Problems of Pooling Cross Section and Time Series:

Given cross section data for 20 countries and time series observations for the years 1955, 60, 65, and 69, the question arises as to the proper method of pooling the cross section and time components in order to estimate equations (5), (7), and (14). The issues are best illustrated by the following relationship between some dependent variable (y) and the vector of independent variables x.

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} \cdots + \beta_n x_{nit} + e_{it} \qquad (18)$$

i =1...m countries
t=1...T years

OLS estimation of (18) allows both the variation between and within countries to determine the β_i coefficients. This may pose somewhat of an interpretation problem for the β_i coefficients since the pure cross section component of the sample implies a long-run equilibrium relationship[17] between the x's and y, e.g.,

$$y_i = \beta_0^{cs} + \beta_1^{cs} x_{it} + \cdots \beta_n^{cs} x_{ni} + e_i^{cs} \qquad (19)$$

The values for the x's presumably measure permanent or long-run effects enabling one to argue that country 1 would respond to a price change in the same manner as country 2 after some unspecified period of adjustment.

In contrast, the time series component presumably measures the response to a change in x's in the current period. Holding the country (i) constant

$$y_t = \beta_0^{ts} + \beta_1^{ts} x_{1t} \cdots \beta_n^{ts} x_{nt} + e_t^{ts}. \qquad (20)$$

Thus in combining cross section and time series data, one is forcing equality of β_i^{CS}, the long-run coefficient, with β_i^{ts}, the current period coefficient. The weighted average of the two effects depends critically on the time series variation relative to the cross section variation.[18] Since in these applications the cross sectional variation in the dependent variable greatly exceeds the variation within countries, the combined estimates are still likely to represent moderately long-run adjustments. At any rate, by comparing the pure cross section results for 1969 with those for the cross section, time series sample, one may be able to approximate the importance of this weighting of short and long-term effects.

Even after estimating (18) for the sample of 20 countries at 4 intervals of five years, the researcher is left with little guide as to how long a period do the "long-run elasticities" apply. In an attempt to estimate the rate of adjustment to the long-run estimates, we use pure time series observations at 5 year intervals to estimate the effects of variations in capacity utilization and within process energy input changes. This is accomplished simply by eliminating variation between country means (the long-run error component)[19] which is equivalent to inclusion of country dummy variables (c_i: i=1- - -19) in (18) as follows:

$$y_{it} = \beta_0^{ts} + \beta_1^{ts} x_{it} \cdots \beta_n^{ts} x_{nit} + \gamma_0 c_1 \cdots + \gamma_{19} c_{19} + e_{it} \qquad (21)$$

This formulation imposes a common set of coefficients for observations across countries, but the estimated coefficients measure only the impact of time related changes in a given x_{lit} about its sample mean for each country. By comparison of these short-run estimators in (21) with long-run estimates in (18), one may be able to define a set of adjustment parameters (λ_i)

$$\lambda_i = \frac{\beta_i^{ts}}{\beta_i} \qquad i=1 \ldots n \text{ variables} \qquad (22)$$

In particular, one might expect to find λ values for income effects approaching unity. Alternatively, price coefficients are likely to have low λ's due to the longer adjustment phenomena discussed earlier.

III. METHODOLOGICAL DIFFICULTIES

The implementation of the above approach creates a set of additional problems which do not fit conveniently under the categories of specification and estimation, although they affect one's choice in these matters. To a large part, these problems emanate from the use of aggregated international data. In particular, four potential problem areas emerge. These include errors in variables due to data deficiencies, international differences in tastes, technology, and optimization, problems of simultaneous equations bias, and the interpretation of prices.

1. The Data Base—The Errors in Variables Problem

The above equations are estimated for a cross section of twenty OECD countries including the United States, Japan, and Canada. This group accounts for approximately 85% of the world's petroleum consumption. Fortunately OECD quantity data are available for the eight energy products in the seven sectors discussed earlier and are believed to be consistent and correct.

As noted earlier, time series observations for the 20 countries were drawn for the years 1955, 1960, 1965, and 1969. Data for 1970 are available but were felt to be inferior to the 1969 data, since in mid-1970 petroleum prices rose sharply. Consequently, price observations for 1970 are likely to reflect a short-run disequilibria. In contrast, price data for 1969 are more representative of past years.

The price data came from a variety of sources and no doubt contain substantial measurement errors. For 1969, an OECD price survey[20] provides a fairly comprehensive basis for international price comparisons. As an attempt was made to standardize for product quality differences and quantities. Price estimates for earlier years were obtained by calculating price indexes for the various fuels for each country and thereby estimating earlier years based on the price index and the absolute price level for 1969. In a number of cases, residential price indexes for a particular fuel were used to estimate the industrial price index and vice versa. Even after searching various country's internal statistics, heavy fuel oil, gas and electricity price indexes were unavailable for about 15% of the pre-1969 observations. Rather than simply omitting every country/year observation for which one price observation was missing, a simple regression technique is used to estimate statistically the missing observations. This technique is similar, in principal, to that employed by Kravis, Summers, Heston, and Kennesey in their extensive construction of international price indexes.[21]

The obvious deficiencies of these procedures to estimate price observations prior to 1969 suggests that the pure cross-section results for 1969 are likely to be superior to those including the time series component. In addition, these problems may be so serious as to render the time rate of adjustment calculation in (22) meaningless.

2. International Differences in Tastes, Technology, and Optimization

Despite our recognition of the fact that energy substitution possibilities differ significantly depending on their particular use, it was still necessary to aggregate industries where energy-use technology is likely to differ significantly. This problem is particularly acute for energy input into "other industries", which excludes iron and steel but includes other manufacturing uses. Even the existence of an aggregation production function is subject to question. To some extent, inter-country differences in the composition of manufacturing output may be explained by variables reflecting the energy-intensity of the output mix, but this procedure is an inferior substitute for more disaggregated studies.

As for the determination of energy shares, one must implicitly assume in the translog formulation that the energy intensity of the output mix is unrelated to the shares of fuel consumed. Such an assumption may not be warranted since a high proportion of energy intensive industries implies large uses of process heat, the energy use for which inter-fuel substitution possiblilties are the greatest. In other economies characterized by lower proportionate heat uses for energy, the substitution possibilities tend to be more limited. For example, uses dependent on fairly unique properties of the fuel may be important as in chemicals and in plant lighting. In the simple share model in equation (7), we plan to introduce additional variables to reflect the scale of the economy and the energy intensity of the output mix.

Aggregation problems also may manifest themselves in residential fuel uses since this sector includes agricultural and other miscellaneous uses. To correct for such effects, we plan to introduce the share of agriculture in GNP. Again given such aggregation over different energy using technologies, it is uncertain whether these correction factors are appropriate, but they can be introduced in equations (5) and (7). In the specific discussions of estimates for various markets, results of tests which group similar countries will be analyzed to provide additional evidence.

In addition to inter-country technology differences, it is appropriate to question whether the economic agents in all countries minimize costs or at least act under similar regulatory constraints. In analyzing institutional differences, one must distinguish between price and non-price regulatory constraints. All countries use tariffs or direct price constraints of a tariff nature, the firm takes the prices as given and can then pursue the goal of maximizing profits. To the extent that direct regulatory methods introduce non-price constraints on behavior, market prices will not reflect relative scarcities and the estimates of inter-fuel substitution will indicate little price responsiveness. While a study for each particular country would be able to elicit such institutional effects, we must proceed on the assumption they are negligible.

One sector in particular, electricity generation, serves as an example of a case with both significant non-price controls on energy use, and a strong possibility that regulatory methods impede cost minimization. Recently sulphur emission on inputs to power plants have been instituted in many of the countries in the sample. Moreover, these regulations have utilized non-tax mechanisms designed to affect fuel-use directly. Even before air pollution considerations became important, utilities in the U.K. and France had made utility fuel choices on considerations other than cost minimization.[22] In the U.K. it is entirely possible to observe substantially lower prices for heavy fuel oil relative to coal without any impact on fuel input to utilities.

Finally, international differences in tastes may manifest themselves in residential demand for energy and in the determination of motor gasoline demand. For example, Europeans may consume less gasoline for reasons other than price and income. These other factors may include international differences in car size, suburbanization, and highway infrastructure—all of which may depend on taste or other inherent differences between countries.

Estimation of cross-section, time series samples with dummy variables eliminates such international differences as well as long-run effects elicited by between country variation. Nevertheless, they probably serve as a weak test. Significantly different results involving reversals of coefficient signs would lead one to suspect the sample heterogeneity is so great as to undermine the utility of that equation. For example, suppose the price coefficient in a pure cross-section is positive and takes on the expected negative sign in the cross-section, time series analysis including dummy variables. In the former equation, we would expect that gasoline prices are serving as a proxy for omitted inter-country variables.

3. Problems of Simultaneous Equations Bias

It is well known that when using OLS the introduction of an endogenous variable as an explanatory variable, will result in inconsistent estimators. In this case it can be pointed out that the price of energy is not determined independently of the quantity demanded. In fact, one might posit the following supply-demand model for a particular fuel in which x and z are exogenous variables.

$$q_t^d = \alpha_0 + \alpha_1 P_t + \alpha_2 X_t + e_t \qquad (23)$$

$$q_t^s = \beta_0 + \beta_1 P_t + \beta_2 Z_t + u_t \qquad (24)$$

$$\frac{\Delta P}{P_t} = \lambda[q_t^d - q_t^s] + v_t \qquad (25)$$

In (25), supply (q^s) and demand (q^d) quantities determine price changes which in turn simultaneously determine supply and demand. The error term e_t, which is necessarily correlated with q^d, affects prices in equation (25), thereby implying that $E(p_t, e_t) \neq 0$ and implying that OLS demand function estimators are biased. By a similar argument one can demonstrate their inconsistency.[23]

Does one conclude from the above example that ordinary least squares estimators are undesirable? The answer depends to a large extent on the time frame in which prices are determined and the role of exogenous factors in determining prices.

In explaining short-run price variations, both supply and demand factors play a vital function. Demand, owing to its highly inelastic nature in the short-run, may even dominate causing one to reverse the functional form of (23) and to argue that in the short run q^d determines p, but not vice versa. It was precisely due to these short-run phenomena that observations for 1969 were utilized in place of 1970.

In the longer-run, prices are to a large extent set by supply conditions prompting the replacement (24) and (25) with

$$P_t = \gamma_0 + \gamma_1 q_t^s + \gamma_2 Z_t + u_t \qquad (26)$$

Over the longer time horizon, competitive pressures may force firms to price at long-run marginal costs. In the case of a perfectly competitive, constant cost industry, long-run equilibrium prices are completely supply determined. Over the period, the evidence is mixed as to the validity of this assumption. In the U.S., where entry to petroleum exploration and coal mining is relatively free, the petroleum industry faces rising unit costs, while the constant cost assumption seems plausible for coal, given safety and environmental regulations. In contrast to the U.S. petroleum situation, over the sample period the international petroleum business was probably a constant cost industry, but faced restricted entry.[24] The latter lead to pricing above marginal costs—a decision depending in part on the price elasticity of demand. Nevertheless, it seems clear that to the extent monopoly power on behalf of the international oil companies existed, it did not lead to collusive short-run profit maximization. Rather entry conditions and price coordination problems are probably much more important in explaining crude oil prices thatn the elasticity of demand in a simple monopoly price model since the latter would not explain pricing over an inelastic range of the demand curve. Thus, to the extent that price observations reflect long-run equilibrium phenomena rather than short-run variations, the problem of simultaneous equations bias would appear to be reduced markedly.

In addition to long-run competitive pressures reducing the simultaneity between demand and price, it is important to recognize the role of exogeneous factors in price determination. For many countries, one can legitimately argue that the price of crude oil input is exogenous, being determined in world markets. Similarly, tanker rates are set by world market conditions. To a lesser degree, the same argument can be made for coal. In addition to the argument of the country vs the world market, institutional restraints in the form of tariffs greatly affect the price of petroleum products. In the case of tariffs, which are usually taken as exogenous, it is not completely convincing to argue that these rates are set independent of demand. For example, high tax rates on gasoline in Europe were instituted before a large portion of the public had cars so that it was politically palpable. To some extent, low demand precipitated high tariffs. On the other hand, Europeans have traditionally favored excise taxation as a principal form of revenue. Thus demand factors are only one determinant of tariff rates. Tariffs on heavy fuel oil in much of Europe are no doubt designed to protect coal, recognizing the high cross price elasticities between the two products. The exact level of the tariff is determined primarily by supply conditions for domestic coal and fuel oil. This suggests that while some exogenous price determinants are not truly exogenous, the relationship with demand phenomena in the local country depends on many considerations beyond demand. In view of these considerations, the problem of simultaneous equations bias do not appear particularly serious for the sample chosen.

4. The Interpretation of Prices

Fuel prices play a vital role in the estimation of the demand function in equation (5) and are critical in (7) and (14). Yet the observed prices may be deficient for the problem at hand and lead to deceiving results. Essentially two measurement problems arise. First, some fuel prices may not be market clearing. Second, perfect fuel substitutes lead to indeterminacy.

If prices are non-market clearing, price-output observations fall along a supply curve rather than a demand curve. Consequently, one may be estimating a hybrid, supply-demand equation, which is non-sensical. Problems of non-market clearing prices are particularly pertinent in the case of natural gas. Although U.S. demand for natural gas was met in 1969, more recent observations could not assert this. The OECE data reported prices both for natural gas and for manufactured gas if either were sold in significant quantities. In a

country reporting both prices, which is the appropriate price? While marginal supplies of manufactured gas are probably forthcoming at similar prices, the price for new supplies of natural gas probably exceeds the contract price for old gas. Thus, at reported prices for natural gas, there may be unfilled demand, especially if manufactured gas is selling in the same market at a higher price. In this situation, the price of manufactured gas is the appropriate price. In other situations in which the price of manufactured gas applies for one geographic area of a country and natural gas applies to some other (e.g., as in Canada), the choice is less obvious. This only illustrates that despite efforts to use the appropriate market clearing price, the basis for choice tends to be ad hoc and subject to judgmental error. We have generally attempted to use the higher of the two gas prices unless the higher price had a very low quantity associated with it.

Besides measuring the proper market-clearing price, the researcher may find an indeterminacy between prices and outputs. Indeterminacy is a matter of degree, but let us begin by considering the extreme case. Suppose two fuels are perfect substitutes, causing the firm's isoquants to become linear. If $(Pf_1/Pf_2) > (MP_1/MP_2)$, where MP_i is the marginal product of fuel, fuel 2 will control 100% of the market and conversely if $(Pf_1/Pf_2) < (MP_1/MP_2)$. If $(Pf_1/Pf_2) = (MP_1/MP_2)$, market shares are indeterminate. In fact, there are obvious reasons why the producers of both fuels attempt to equate the relative prices and marginal products.

Since we observe few cases in which market shares are either zero or unity, indeterminacy appears to be quite serious at first glance. However, two factors tend to mitigate this problem. First, it is unlikely that fuels are perfect substitutues over the complete range of the isoquants. Energy is simply not fungible for all uses since the choice of a particular fuel depends on its specific attributes in addition to its price on a btu basis. Even for process heat, which focuses primarily on the cost per btu, the aggregate isoquants are unlikely to be linear over the complete range, but instead have linear segments or indeterminate ranges. Process heat techniques which make two fuels perfect substitutes for one set of relative prices are unlikely to exist for all process heat purchasers. Thus unique fuel characteristics, together with varying energy use techniques seem more likely to create ranges of indeterminacy rather than complete indeterminacy.

A second factor mitigating indeterminacy is the variation of relative prices within a country even when the isoquants are linear. These relative price variations arise from cost differences in transportation which are particularly important in the case of heavy fuel oil and coal—the two principal competitors for process heat. Assuming some spatial continuum of demand, the higher the spatial variance of relative prices, the lower the range of indeterminancy of the market share. This observation suggests that the more geographically dispersed a nation is, the greater the price variations and the lower the variance of the error term in the regressions. If the variance of the error term is a function of geographic dispersion, as one would suspect, then the OLS estimates may be inefficient. This might suggest using a generalized least squares procedure giving greater weights to observations from the U.S., Canada, etc. and less to the Netherlands, Ireland, etc. The importance of this factor will be resolved empirically.

In sum, indeterminacy does not appear to affect the independence of the error term, but it does suggest a large variance associated with the error term. One simply cannot expect a high degree of precision from equations (7) and (14).

IV. SUMMARY

This study is motivated by the limitations of time series analysis to elucidate between and within process changes in response to higher crude oil prices. In contrast, the use of pooled international data, containing between country variation as well as within country, time series variation, offers exciting possibilities for estimating these long-run responses. A two step estimation approach is planned in which the first step determines aggregate energy demand for a given sector and the second step estimates the market shares of particular fuels. In the latter step, we plan to test two alternate models which differ significantly in the extent to which they draw on economic theory. Finally, a procedure is outlined for defining the rate of adjustment to the "long-run."

The adoption of this approach is not a costless one, however. Although the simultaneous equation bias problem is present in even time series analysis, additional problems are attributed to the use of an international sample. First, the quality and comparability of price data introduces a serious objection. Second, international differences in tastes, technology, and optimization suggest that this study is only a first attempt and should be followed by explicit introduction of such effects. Third, problems of the proper interpretation of prices and ranges of indeterminacy indicate fuel share equations are likely to leave rather large unexplained variation.

As for the policy application of these results, an appraisal must of course wait on the empirical results. Nevertheless, from the above discussion, several observations seem warranted. As a short or intermediate term

forecasting tool, this approach is ill-designed; rather it is only in longer term exercises that the approach is tractable. The inability of this procedure to pinpoint how long a period is required for these process changes limits its applicability even for long term exercises, but given the state of the art this is by no means a fatal objection. Also, this approach is more likely to yield valuable insights for a group of countries than for any one in particular since omitted inter-country differences probably average-out over countries.

FOOTNOTES

* The author is indebted to F. G. Adams, a collaborator in much of the work discussed in this paper.

[1]The term within and between process changes was first utilized by John Enos to describe technological change. This distinction seems equally useful in an energy efficiency context. One important finding of Enos is that "within process" technological change exceeded "between process" change, suggesting that a putty-clay description of energy intensiveness is likely to be an over simplification. See John Enos "A Measure of the Rate of Technological Progress in the Petroleum Refining Industry," *Journal of Industrial Economics,* IV, June 1958, pp. 180-197.

[2]For a discussion of various estimation procedures for distributed lags, see P. J. Dhrymes *Distributed Lags: Problems of Estimation and Formulation* (San Francisco; Holden Day, 1971).

[3]Griliches' findings of the structural instability of estimators by existing estimation procedures would appear particularly acute for describing longer-run phenomena. See Z. Griliches "Distributed Lags: A Survey," *Econometrica,* 5 1967, pp. 16-19.

[4]Data limitations prevent the estimation of a translog price possibility frontier for aggregate inputs such as energy, capital, labor, and materials. We will, however, propose its application for the fuels within the energy aggregate. For an application of the translog approach, see L. R. Christensen, Dale Jorgenson, and L. L. Lau "Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics,* February, 1973, pp. 28-45. For an example of the approach precluded here, see Ernst Berndt and David Wood, "Technology, Prices, and the Derived Demand for Energy," unpublished manuscript, December 1973.

[5]Verleger uses a similar minimum fuel price variable in the determination of fuel inputs into electricity generation. See Philip Verleger "An Econometric Analysis of the Relationships between Macro Economic Activity and U.S. Energy Consumption," in *Energy Modeling,* ed., Milton Searl (Washington, Resources for the Future; 1973) pp. 94-97.

[6]Data Resources, "DRI Report to Energy Policy Project," Ch. 4 Demand Analysis by R. L. Christenson and Dale Jorgenson, unpublished manuscript p. 4-13-14.

[7]This is a commonly understood property of OLS estimators which can be easily proven for the single variable case as follows:

$$(1)' \quad Y_{it} = a_i X_t + \beta_i + u_{it} \qquad \begin{matrix} i=1 \ldots n \\ t=1 \ldots T \end{matrix}$$

let

$$x_t = X_t - \bar{X}$$

$$y_{it} = Y_{it} - \bar{Y}_i$$

$$(2)' \quad \text{Since} \sum_{i=1}^{n} Y_{it} = 1$$

$$(3)' \quad \sum_{i=1}^{n} y_{it} = \sum_{i=1}^{n} Y_{it} - \sum_{i=1}^{n} \bar{Y}_i = \sum_{i=1}^{n} Y_{it}$$

$$- \frac{1}{T} \sum_{t=1}^{T} \sum_{i=1}^{n} Y_{it} = 0$$

Rewriting (1)′ in deviations about sample means, we get:

$$(4)' \quad y_{it} = a_i x_t + u_{it}$$

Since the OLS estimator of a_i is

$$\hat{a}_i = \frac{\sum_{t=1}^{T} y_{it} x_t}{\sum_{t=1}^{T} X_t^2}$$

Summing the slopes across all n equations:

$$(5)' \quad \sum_{i=1}^{n} \hat{a}_i = \sum_{t=1}^{n} \frac{\sum_t y_{it} x_t}{\sum_t x_t^2} = \frac{\sum_t x_t \sum_n y_{it}}{\sum_t x_t^2} = 0 \text{ by } (3)'$$

The intercept term sums to 1:

$$\hat{\beta}_i = \bar{Y}_i - \hat{a}_i \bar{X}$$

$$\sum_{i=1}^{n} \hat{\beta}_i = n \bar{Y}_i - \bar{X} \sum_{i=1}^{n} \hat{a}_i$$

by (2)′ (3)′ and (5)′

$$\sum_{i=1}^{n} \beta_i = n \bar{Y}_i = 1$$

[8]P. J. Dhrymes, *Econometrics* (New York, Harper and Row, 1970) pp. 159-160.

[9]Christenson, Jorgenson, and Lau, *op. cit.*, pp. 28-45.

[10]See Data Resources Report to Energy Policy Project. Unpublished Manuscript. Also see Berndt and Wood *op. cit.*

[11]We illustrate for the case of three fuel inputs (s=3) merely for convenience.

[12]For a mathematical statement, see "DRI Report to Energy Policy Project: Ch. 3, Production Structure," by Ernst Berndt and Dale Jorgenson, unpublished manuscript pp. 15-20

[13]H. Uzawa, "Production Functions with Constant Elasticities of Substitution," *Review of Economics Studies,* October 1962, pp. 291-299.

[14]Berndt and Wood, *op. cit.*, p. 6.

[15]R.G.D. Allen, *Mathematical Analysis for Economists,* (London, MacMillan, 1938) pp. 503-509.

[16]E. Malinvaud, *Statistical Methods of Econometrics* (Amsterdam: North-Holland, 1970) pp. 325-373.

[17]For the distinction between short and long-run effects, see H. S. Houthakker, "New Evidence on Demand Elasticities," *Econometrica,* Vol. 33, No. 2, April 1965, pp. 277-288.

[18]In fact, the error component model would argue that the error term e_{it} can be decomposed into a random country error term (u_i), random time error time (τ_t) and complete random error (v_{it}) as follows:

$$e_{it} = u_i + \tau_t + v_{it}$$

Maddala illustrates the application of generalized least squares to purge the error term of country and time related error. The interpretation of intercountry differences as random phenomena is contrary to our interpretation that these differences are systematic and to be explained. Thus Maddala's generalized least squares procedure would appear inappropriate. See G. S. Maddala "The Use of Variance Components Models in Pooling Cross-Section and Time Series Data," *Econometrica,* 39, March, 1971, pp. 341-358.

[19]See Maddala, *op. cit.*, p. 343.

[20]O.E.C.D., "First Survey on Energy Price Statistics," Paris, September 1970.

[21]I. E. Kravis, Z. Kenessey, A. Heston, and Robert Summers, *A System of International Comparisons of Gross Product and Purchasing Power* (Baltimore: Johns Hopkins Press) forthcoming.

[22]M. A. Adelman, *The World Petroleum Market* (Baltimore: Johns Hopkins Press 1972) pp. 227-228.

[23]See Dhrymes *ibid.*, p. 174-175.

[24]See Adelman, *op. cit.*, pp. 45-100.

SUMMARY OF DISCUSSION

Differences in the transportation systems among countries may invalidate combining them into one equation. While the models constrain the market shares to sum to one, the market shares of particular fuels may not fall in the 0, 1 interval. This may be especially serious for simulating results with higher prices, as the market shares may be greater than one and some may be negative. As an alternative, a logit share model was suggested. It was also suggested that the assumption of the independence of irrelevant alternatives be used. This assumption means that when estimating relative market shares of two fuels, the prices of other fuels can be ignored.

The applicability of this model to the electric utility industry is limited because it does not explicitly take into account fuel consumption patterns determined by long term capital commitments. For the electricity sector the long run may be much longer than 10 years.

DISCUSSION

GRIFFIN: And, now, I just would like to throw it open for discussion. Incidentally, if any of you happen to read my paper in greater detail and have the time to sit down and try to draft a set of criticisms, I'd appreciate receiving them, because I've just now really gotten the estimation out of this model, and in no sense do I feel wedded to this particular formulation.

HUDSON: The thing that disturbs me about using cross section data is that there are so many differences between countries. Europe hasn't gotten the inter-state highway system; it doesn't have General Motors advertising its products on television day after day. These countries may not be able to afford to take long holidays as Americans can. There are so many things in the background.

GRIFFIN: You are right. Everything that you've mentioned so far, is such that I would think that perhaps income would be a fairly good proxy for it. The basic problem is those international differences which are not explained by income and price variables.

HUDSON: I think the omission of the inter-state highway system is a very serious thing.

GRIFFIN: Perhaps you want to get off onto the gasoline paper which Adams presented. We introduced things like urbanization in an attempt to try to catch some of these omitted intercountry differences. I agree with you. I think that's a serious problem. One of the limitations is that we can try to make these adjustments, but one of the difficulties is that we don't know much about the institutional make-up of a given country. I'm sure someone from *that* country could provide much more insight about what ought to be in those equations than the *a priori* judgment we make. I think you have a valid objection. I don't know what you can do about it except try to correct it.

KAUFMAN: Jim, Marty was speaking about market shares and that it is a multinomial process. Even if we grant that we don't want to go to that level of disaggregation, the fact is that the market shares do sum to unity and each of them lies between zero and one. You may be lucky in the estimation procedure and find that you get means that satisfy those properties.

GRIFFIN: It's a property of the least squares method that market shares sum to unity.

KAUFMAN: Nevertheless, the basic formulation is one in which, in principle, M_1 and M_2 and so on are not constrained to lie in that interval. An alternate formulation would be to go to a logit formulation of this equation. That introduces other difficulties, I would imagine. But at least, from the point of view of basic structure, you're not faced with the unfortunate artifact of getting proportions that are negative or greater than one. The logit formulation, of course, has a straightforward, interesting, neat, probabilistic interpretation. It ties in with the kind of suggestion Marty was making in viewing the process, and the expectation can be interpreted as a probability.

GRIFFIN: That's an interesting idea. When you estimate, in this formulation, you may find that your market share conditions are met, but then when you start simulating with it with higher fuel prices, you end up with market shares greater than one for some fuel and negative market shares for others. The usual response is that you set up constraints and if some market share is less than zero, you set it to zero, and so forth.

BAUGHMAN: Well, another thing that you can bring in, and it's not clear that it really holds, is something called the assumption of independent irrelevant alternatives. What that basically says is that when you're estimating an equation for M_1/M_2, you can forget about the prices of other fuels because all you're estimating is a relative conditional probability that we choose M1 or M2, given that we choose one of these two. Thus it doesn't depend on the other prices. You follow what I'm saying?

KAUFMAN: If you assume that these things are perfect substitutes, you can simplify it even further. You don't necessarily have to assume that, but if they are perfect substitutes, then you wouldn't expect the price of a third fuel to effect the ratio of market shares.

GRIFFIN: Well, I don't want to make that restrictive assumption. I really think that there is a set of ranges over which there are substitutes.

McCALL: Jim, apparently you don't include electricity among the fuel in these sectors?

GRIFFIN: I do and I don't. In the manufacturing and transportation sectors, yes, electricity shares are included. Now, when I get to the residential sector, I plan to treat residential electricity from consumption separate from the fuel shares in this sector because I don't think there's a lot of substitution, but I do intend to examine for that. Certainly, it has a much different growth pattern over time.

VERLEGER: I think that the one thing that bothers me about the fuel share approach is when it is used with the electric utility industry and is not corrected for the capacity of burning different fuels because a choice between fuels was made at the capital stage. It will generally determine the usage of that fuel for between five years and 20 years, depending on the vintage of the capacity. I guess in the long run, the problem will work out, but the intervening period can be ten years, in which the choice may be determined by fuel availability.

GRIFFIN: That was said in my conclusion. It's just not designed to handle these short-run problems. I suspect that the long run may be longer than ten years. It could be 15 to 25 years for a lot of these processes.

KAUFMAN: Let me ask you just as a follow-up: I'm a little bit worried about what this does to the shape of the cost share, if you go to the logit formulation. Do you get into any trouble later on in the sense of having to get much more complicated?

GRIFFIN: I can't do it in Jorgensen's framework, but I could presumably do it here, because I'm not really beginning with a price possibility frontier. I'm sort of invoking this as a reasonable looking function a priori.

BENENSON: There are a couple of papers on the back table. One is a summary of some remarks that were made this morning. If you have any comments to make on them, we'd like to see them. The other is a memo which I believe Paul Craig sent to each of you. It has a couple of questions in it, and I thought it would be helpful to look at them again to make sure that they are considered tomorrow. We start promptly at nine, and perhaps, if we can fit in three papers in the morning, we might be able to finish a little earlier tomorrow afternoon.

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ENERGY SYSTEMS: MODELING AND POLICY PLANNING*

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SUMMARY

Baughman drew his presentation from two papers: 1) Energy Systems: Modeling and Policy Planning, and 2) Interfuel Substitution in the Consumption of Energy in the United States.

In the first paper, an overview of the major issues pertinent to the formulation of national energy policy is presented. Some of the issues covered are the nonrenewability of fossil fuels, imports, national security, balance of payments, new technologies, interfuel substitution, environmental impacts, and economic welfare.

The nature of the modeling task and the steps it is composed of are described. They are 1) development of conceptual models, 2) identification of data needs, 3) estimation of parameters, 4) assessment of model validity, and 5) testing, prediction, and policy analysis. Models are further classified according to purpose and level of aggregation.

An examination of the methodological approaches available for structural specification, estimation, and use in policy analysis is given. Alternative ways in which models can be used for policy planning through simulation and optimization techniques are presented. Rather than focusing on the consequences of using a particular policy, Baughman emphasizes determining what policy should be used to attain a certain outcome. The selection of policy variables is also discussed.

The second paper contains the theoretical framework and results of a descriptive model of energy supply and demand. Demand is broken down into residential, commercial, industrial and transportation sectors. Coal, oil, natural gas, and nuclear fuels are distinguished on the supply side. The time horizon of this model is approximately fifteen to thirty years. The model is national in scope; the lack of regional detail is a drawback. The parameters in some cases are developed from engineering estimates. Baughman cautioned that a great deal of judgment must be exercised when estimating parameters and extrapolating trends in cost of supply and growth rates for demand. The model is used to establish the consistency of estimates and projections and to maintain a system of accounting. A criticism of the model is that it may incorporate the subjective judgment of the model builder. Baughman noted three areas in which more regional detail is being developed: 1) demand for fuel in the residential and commercial sector, 2) electrical supply, and 3) coal supply.

Baughman used his interfuel substitution study as an example of the model building process described in his modeling and policy planning paper. He presented two examples of model construction which illustrate how the choice of a model depends upon the particular characteristics of a sector and the data availability.

In the first example, the residential-commercial sector, fuel choice is a two-step process. The first decision is to fulfill some functional need. The second decision is to choose a particular fuel or fuel-burning technique to fulfill this functional need. These choices must be modeled to describe the demand for fuel in the residential and commercial sectors. To do this, Baughman formulated a consumer choice index assumed to be a linear function of the fuel characteristics, such as prices, capital costs, and climatic variables. He then tried to estimate, by regression analysis, the relative probability of choosing between types of fuel. His objectives are 1) to estimate appliance choices and 2) to estimate the fuel split of aggregated energy consumption among the three fuels used in the residential and commercial sectors. (Different data sets are used to make these two estimates.) Ultimately, the fuel split equations are combined with the aggregate consumption equations to project residential and commercial consumption through 1980.

The model is applied in four areas: 1) saturation elasticity in the residential commercial sector for various appliances, 2) aggregate fuel consumption in this sector, 3) fuel choice decisions in the industrial sector, and 4) plant choice decisions in the electric utility sector. Baughman discussed the results from the first application. A conceptually more appealing approach for estimating residential-commercial consumption is to separate the capital stock decision and the utilization decision. This is the suggestion Verleger outlined in more detail.

The second example Baughman discussed is the model for electricity supply, for which he used engineering estimates. This entailed the adoption of the normative (i.e., goal oriented) idea of minimizing cost given a particular load curve, and the incorporation of the behaviorial characteristics of utilities trying to meet this load curve. Since utilities use optimization techniques to make decisions, a descriptive model of this sector should account for this type of behavior.

Baughman concluded his talk by suggesting two areas for further research: 1) linking macro models that account for political intervention such as taxes and subsidies with the micro models that describe fuel supply and demand; and 2) coupling optimization techniques such as linear programming and optimum control with descriptive models such as the one he described.

* * *

I. INTRODUCTION

The purpose of this paper is to provide a coherent overview of modeling in the energy field and its implications for the formulation of national energy policy

The energy modeler faces a formidable challenge. He must be able to identify the fundamental issues confronting his planning task: not only at the economic and technological level, but frequently at the institutional, sociological and political level as well. He must be aware of the conceptual and theoretical foundations of model-building and of the methodological alternatives at his disposal. Finally, he must be able to convey the information derived from the modeling effort in a way which will be useful to the planning authorities and other decision-making entities with which he must interact.

Energy policy planning is truly a multidisciplinary field. The systems approach, emphasizing as it does the interrelated nature of decision-making at all levels, is particularly appropriate to serve as a framework for energy modeling. Indeed there are few other areas which are as rich a source of immediate challenge and potential reward to the systems analyst.

The structure of the paper is as follows: in section II, we present an overview of the major issues pertinent to the formulation of national energy policy; in section III the nature of the modeling task and the various steps that it is composed of are described; section IV is devoted to an examination of the various methodological approaches available to the energy modeler in the various phases of his work; in section V we discuss the alternative ways in which models can be used, through simulation and optimization techniques; finally, we present in section VI an overview of the modeling activities of the M.I.T. Energy Laboratory.

II. ISSUES IN U.S. ENERGY POLICY

The pervasive effect of energy in contemporary society largely accounts for the rapid rise of national debate on energy policy to its present preeminent position in the public consciousness. The debate is wide ranging for there is no shortage of controversial issues. Natural gas—as a result, it is argued, of the price regulation for that fuel—is in short supply. Emissions standards and environmental constraints have forced major industrial consumers to shift consumption from coal to lesser polluting petroleum products: low sulfur oil and natural gas. Safety considerations have brought about numerous legal actions delaying or restricting the use of nuclear power plants. There is growing concern over the fact that nearly one third of our present oil supply is imported, and the future outlook is that this may increase to half or more of the oil supply by 1985, if present trends continue.

Continually, actions are discussed, proposed, or enacted to meet and ameliorate these problems. Environmental standards are being relaxed or delayed to ease current shortages. Major new moves in coal processing and conversion are being considered. The conservation ethic has started. Numerous new technologies are being assessed and evaluated for their potential of further development. The practice of natural gas price regulation is receiving much attention, and various deregulation schemes are being advocated. Indeed, major new policy moves in all areas of pricing, taxation, and research and development with respect to various fuels are continually being put forward.

The energy system is a large, complex, and interconnected system. Its multidimensional characteristics, at least from the point of view of policy and industry planners, make the implications of action in any sector on the total system at large extremely difficult to understand. For instance, it is true that for many uses in our country the competing sources of energy are highly substitutable. This means that one source of energy can accomplish the user's task as well as another. In 1964, the Energy Study Group wrote[1]:

> "While there are some markets for which only one energy form is now economical, as much as 95 percent of total U.S. energy is consumed for purposes in which several or all of the primary energy sources are potential substitutes (directly or through conversion)" . . .

The user under these conditions of substitutability must choose one fuel over another. His choice may

be influenced by price, but also such things as convenience in handling, cleanliness, and availability can enter into his decision-making process. The high degrees of substitutability characteristic of the sources of energy means that one cannot discuss the supply, demand, and price of a given fuel without also considering the effects on other fuels.

When this is compounded by the effects of changing technologies, resource availabilities, regulatory frameworks, and national policy, it is clear that a comprehensive analysis of the future outlook for energy supply, demand, and fuel prices in the U.S. is an enormously complex undertaking. More specifically, some of the issues that must be interrelated in the analysis of planning options are:

1. Non-renewability of fossil fuel resources.
2. System inertia, lags and the time required for adjustments.
3. Transport and regional characteristics of the system.
4. Imports, national security, and balance of payment problems.
5. New technologies, their role and impacts.
6. Interfuel substitution, and substitutability.
7. Environmental impacts (air, water, land, local vs. national).
8. Energy costs and resource distribution.
9. Financial requirements.
10. Economic welfare.

The reason that models of the energy system are needed is because a complete analysis of these interactions is simply impossible when rapid action is necessary.

An obvious question, especially if you're a free market economist, is why bother with regulatory tools? Many authorities assert that the gravest problems we face in the energy sector are the result of too much, not too little, regulation. In many cases this view is based upon the unsatisfactory results of regulatory actions implemented after an incomplete analysis of the issues—the FPC regulation of interstate sales of natural gas is an example. Nevertheless, it is unwarranted to conclude from this that all regulation is counterproductive.

It is true that under the conditions of perfect competition, the operation of the market system will result in optimal allocation of resources (maximizing producers' profits and consumers' utility). In many sectors of economic activity, however, and most strikingly in the energy sector, there exists a variety of reasons for which the market system may fail and resources may not be utilized efficiently. Some of the conditions that dictate the necessity for some sort of central authority to coordinate and guide the behavior of the many economic entities in the energy sectors are:

1. Oligopolistic market structures.
2. Negative externalities (such as pollution).
3. Existence of natural monopolies (e.g., electricity).
4. Non-renewability of resources.
5. Extra-economic goals (such as independence from foreign supply sources).

Under these conditions, a coordinating agency must intervene. There are two fundamental levels at which policy alternatives and planning options are proposed, assessed, formulated and implemented: i. Policy-making level; ii. Planning level. First, the policy-maker must identify the many dimensions of the overall strategic goals. The announcement of Project Independence is an example of such a policy decision. Then it becomes the responsibility of the planner to synthetize and analyze the alternatives for achieving the goal. The weighing of various R & D strategies, pricing policies, and conservation measures aimed at reducing imports requirements exemplifies the role of the planner in connection with Project Independence. It is at the planning stage that models provide a means to establish trade-offs between the effectiveness and potential adverse side-effects of the implementation alternatives. The recent M.I.T. evaluation of the economic implications of energy self-sufficiency [1] is an example.

In the next section we describe the various stages in the process of model development.

III. THE NATURE OF MODELING

The development of credible and reliable policy analysis models is a long and arduous process. At least five interrelated steps must be undertaken and usually many iterations through the steps must be done before the development is complete. These five steps can be summarized as follows:

1. Development of conceptual models.
2. Identification of data needs.
3. Estimation.
4. Assessment of model validity.
5. Testing, predictions, and policy analysis.

The first step is as much related to problem definition as it is to the actual development of models. Basically, it consists of pulling together the set of theoretical relationships (behavioral, economic, or whatever) that are needed to address the issues one intends to analyze in step 5. It is in this step that issues such as simplifying assumptions, aggregation, time scale, model boundaries, and feedback structure must be addressed and related

to what one intends to accomplish in step 5. The completion of this step forms the theoretical underpinnings of the model to be constructed in the following steps and guides the activity to be undertaken therein.

Once step 1 is complete, a better idea is had of the data needed to estimate the model (quantify the relationships). Steps 2 and 3 are closely related, in that availavility of acceptable data strongly influences the estimation procedures to be applied. One can think of step 3 as essentially putting numerical values to the theory developed in step 1, where the techniques used can range all the way from rigorous statistical analysis to engineering analysis and judgement, depending on the circumstances. However, depending on the techniques used in the estimation process, step 3 can overlap with step 4.

Step 4 is crucial in the development process, for it is here where one must test the validity of the quantified theorities against reality. The model at this stage is nothing more than a mathematical description interacting forces that occur in reality. Whether it is valid depends upon whether: 1) the theory is correct; 2) the numbers are correct; and 3) the simplifying assumptions are valid. To obtain a useful tool, a model must pass all three tests.

Step 5 is the most important. It is the issues to be analyzed that guide the whole exercise. It is in light of these issues that judgment must be exercised as to whether the assumptions and compromises made are acceptable and in order to verify the applicability of the final product it must be tested against these objectives.

In a broad sense, analytical models can be classified according to two basic characteristics: a) Intent or Purpose; b) Level of Aggregation. Traditionally, analytical models are classified according to purpose into *descriptive* or *positive* models and *prescriptive* or *normative* models. For instance, a forecasting model would be considered to be descriptive, whereas an optimizing model would be taken to be prescriptive. In terms of the ultimate goal of policy planning, however, this classification is not fully convincing. There are many examples of models that use an optimization framework but which are not even primarily intended for policy formulation (e.g., Nordhaus [2]). The first precondition for a model to be truly useful in policy planning is that it provide a sufficiently accurate representation of the real world—indeed that it be descriptive. Furthermore, as we shall argue below, an optimization framework need not be aimed at prescribing a unique set of policy instruments.

As far as aggregation levels are concerned, several dimensions can be identified in regard to a classification of analytical models: *sectoral* aggregation, *regional* aggregation, and aggregation *in time*. Much work is currently underway on the application of various methodologies to descriptions of energy supply and/or demand at all levels of aggregation [3], [4]. The following sections briefly compare and contrast some of the methodological alternatives being applied and relate these to the associated intent or purpose to which the methodology is best suited.

IV. MODELING METHOLOLOGIES

The inherently complex and multi-faceted nature of energy policy issues dictates the necessity for an eclectic approach to modeling. What follows is not an attempt to provide an exhaustive list of the tools available to the energy modeler. Rather, a general overview which will highlight the most promising avenues will be given.

For a discussion of modeling methodologies we will group the five steps of the modeling process described above into three major categories, which we point out again, are closely interrelated:

a. Structural Specification (step 1)
b. Estimation (steps 2, 3, and 4).
c. Use in policy analysis (step 5).

a. *Structural Specification*

Various segments of the body of economic theory provide a rich source of conceptual guidance in the crucial step of abstracting the desired relevant features from the real world into mathematical formalism. In a field as closely interconnected with the mainstream of economic activity as is the study of energy dynamics, recourse to economic theory at one stage or another is almost mandatory. Such areas as the neoclassical theory of investment, the behavioral theory of the firm and the theory of consumer behavior, address themselves to issues that lie at the center of any attempt to capture the essential dynamics of energy supply and demand in an analytical framework. At a more aggregated level, the theory of multi-sector models and other generalizations of dynamic input-output analysis appear potentially useful.

Even after a choice has been made as to the levels of sectoral, regional and time aggregation, and a theoretical framework has been selected, there remain the questions of parameter variability and uncertainty. Are the parameters constant or time-varying? Is there explicit consideration of adaptivity? Will explicit descriptions of uncertainty be incorporated in the form of stochastic processes? These are questions that must be resolved before the structural specification of the model can be considered complete. A remarkable

demonstration of the power of stochastic modeling, for instance, can be found in the study of oil and gas exploration by Bradley and Kaufman [5].

The controversial efforts of Forrester and his followers in the field of system dynamics [6] deserve mention at this point. The two main features of this approach are the emphasis on feedback concepts borrowed from engineering and its intent to serve as a carefully constructed guide to the difficult process of translating intuitive and judgemental knowledge into equations. Often criticized for its shortcomings as a theory—which it never purported to be—we feel that perhaps the greatest single contribution of system dynamics is the philosophical breakthrough it achieved in helping to launch the machinery of analytical thought to the service of the socio-economic disciplines, at the level of policy analysis.

b. *Estimation:*

In the widest sense, estimation is a scheme to extract information on given quantitative entities—the *parameters*—from raw data. For our purposes, the parameters of interest are those defined in the structural specification of the model.

The least sophisticated method of relevance to energy modeling consists of what can be termed *engineering estimates.* These are usually obtained from historical data and judgemental insight combined in various ad-hoc ways. Whereas in most cases they cannot be considered to be more than educated guesses, there are instances where they provide the only alternative available: for instance, modeling efforts in the field of new energy technologies—such as the production of synthetic fuels—must rely on engineering estimates, since historical data are non-existent.

The use of statistical estimation techniques in the context of micro-economic and macro-economic models has given rise to the body of knowledge known as *econometrics.* Although in its methodological corpus it achieves varying degrees of sophistication, a large fraction of applied work centers around ordinary least-squares estimation in a single-equation, static framework. For example, a recent survey on econometric studies of investment indicated that "the great majority . . . of the estimates of econometric equations for investment are obtained by single-equation least-squares methods . . .[1]". A comprehensive overview of the state of the art can be found in Theil [7] or Johnston [8].

In the literature of system and control theory, the estimation of numerical values for system parameters is termed *system identification.* It is usually assumed that the underlying system structure is expressed in state-space form. Some of the advantageous features of the system identification approach are that it is set in a multi-variable, recursive framework, it can handle non-linearities and time-varying parameters, it directly allows for explicit modeling of measurement noise in a straightforward fashion, it allows for the incorporation of unobservable quantities in the model (e.g., discount rates, expectation variables, excess demands), and it can directly estimate unknown parameters in the probability distributions of stochastic variables. For a review of similarities and differences between system identification and econometric methods, the reader is referred to Mehra [9]. Although system identification algorithms—for example, based on maximum likelihood concepts—have appeared in the engineering literature for over a decade, the application to a socio-economic systems has been extremely limited. For an application to a system dynamics model for environmental planning, see Young, Arnold and Brewer [10]. Maximum likelihood identification techniques were used in a dispersion model of atmospheric pollutants by Desalu [11]. For a description of a good software package based on standard maximum likelihood concepts, see Peterson and Schweppe [12].

c. *Use in Policy Analysis:*

It is our belief that the theories of mathematical optimization provide a robust methodological basis for the use of analytical models in policy planning. The fields of linear and non-linear programming, integer programming, statistical decision theory and the theory of optimal control have a potential range of applications in policy planning greater than has been achieved in the past. A discussion of the connection between optimization techniques and policy planning is undertaken in the following section.

V. SIMULATION, OPTIMIZATION, AND POLICY PLANNING

The role of a model in the policy planning process is essentially limited by the inherent distinction between the roles of the planner and policy-maker. In a strict sense, it is the concern of the planner to synthetize and identify efficient trade-off patterns among a certain set of attributes which quantify the consequences of alternative courses of action. At the same time, of course, he must prescribe how the various trade-offs patterns are achievable in terms of specific policy instruments. On the other hand, it will be the role of the policy maker to select the trade-off pattern that is judged most favorable and which will ultimately be implemented. Little benefit would accrue from an attempt to quantify this latter process.

If simulation experiments were costless, then a direct search over the space of policy instruments would provide, given a planning model, all the information required by the planner. This not being the case, what is desired is a tool for constructing the "set of efficient trade-off points" in an economical way.

V.1 THE TRADE-OFF POSSIBILITIES FRONTIER

Suppose that there exists a set of attributes J_i, $i = 1, 2, \ldots, r$ which quantify the consequences of alternative time-paths of the policy instruments over the planning horizon. For illustrative purposes, let us say that $r = 3$ and that

J_1 = imported oil and a percentage of total demand
J_2 = index of aggregate environmental impact
J_3 = present value of capital outlays in the energy sector

Let us define

$$L = L(a_1, a_2, a_3) = \sum_{i=1}^{3} a_i J_i$$

$$a_1 + a_2 + a_3 = 1, a_i > 0, i = 1, 2, 3$$

Consider now the problem of finding the optimal policy instruments that minimize the cost functional $L(a_1, a_2, a_3)$ for fixed a_1, a_2, a_3[3]. Let L^* be the resulting optimal value. As we vary a_1, a_2, a_3, we will generate a parametric representation of the set of efficient trade-off points:

$$\phi(a_1, a_2, a_3) = L^* (a_1, a_2, a_3)$$
$$= a_1 J_1^* + a_2 J_2^* + a_3 J_3^*$$[4]

We define the *trade-off possibilities frontier* as the set of attribute vectors $J = (J_1, J_2, J_3)$ such that there exist $a_1 > 0, a_2 > 0, a_3 > 0, a_1 + a_2 + a_3 = 1$ for which $L^* (a_1, a_2, a_3) = a_1 J_1 + a_2 J_2 + {}_3 J_3$. Thus (J_1, J_2, J_3) is efficient if it can be achieved by optimizing L for some trade-off pattern (a_1, a_2, a_3).

The trade-off frontier ϕ constitutes a two-dimensional manifold in J-space. Clearly, one can think of estimating a functional approximation to ϕ of the form $F(J_1, J_2, J_3) = 0$. The set

$$T = \{(J_1, J_2, J_3) : F(J_1, J_2, J_3) > 0\}$$

constitutes the *feasible region.*

V.2 INSTRUMENT-ORIENTED AND PERFORMANCE –ORIENTED SIMULATIONS

How can the frontier $F(J_1, J_2, J_3) = 0$ be useful to the policy-maker?

Suppose that the policy-maker concludes that the vector of attributes $J^o = (J_1^o, J_2^o, J_3^o)$ summarizes his judgment on what the consequences of a desirable plan should be. Given J^o, the planner can then establish the following:

i. Whether J^o is feasible, i.e., whether $J^o \in T$.

ii. If $J^o \notin T$, or $J^o \in T$ but $J^o \notin \phi$.

i.e., J^o is feasible but not efficient, he can compute $J^{*o} \in \phi$ such that $d = d(J^o, J^{*o})$ is a minimum.

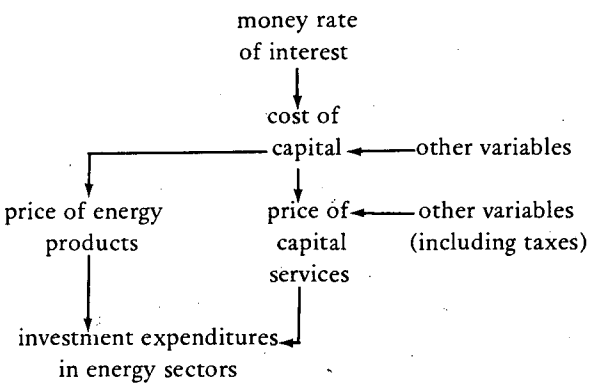
iii. Having selected $J^{*o} \in \phi$, he can find the associated trade-off pattern a_1^o, a_2^o, a_3^o and find the corresponding time-paths of policy instruments which will yield J^{*o}.

The advantages of the approach just described over routine simulation experiments should be clear. What is customarily referred to as simulation is basically an *instrument-oriented simulation* in that it answers the question: What would be the consequence of using a particular policy? The philosophy of our approach using optimal control might be referred to as a *performance-oriented simulation* in that it provides the answer to: What policy should be used to attain a certain outcome? An instrument-oriented simulation results in a J belonging to the feasible region. A performance-oriented simulation always yields a J on the efficient frontier.

V.3 SELECTION OF POLICY VARIABLES

There is obviously no unique choice for the set of variables that are assumed to be subject to control. The various available choices entail different assumptions about the institutional and political constraints and the degree of flexibility and realism that one wishes to incorporate in the model. For example, in order to control investment outlays in the energy sectors, it could be assumed that total investment expenditures themselves are controllable. More realistically, one could think of controlling the determinants of investment, such as prices of energy products, prices of capital services, etc.

Indeed an entire hierarchy of potential policy instruments can be pictured, each level in the hierarchy representing a different degree of direct controlability:



To be precise, we should divide the effects of various policy instruments according to whether they affect primarily the supply side or the demand side.

Supply Side:

For a medium to long-term planning horizon it is convenient to assume—at least initially—that the level of capacity utilization is fixed at some nominal desired value. Thus with respect to the supply side all policy instruments are effectively aimed at acting as investment incentive schemes in one way or another. Three distinct categories can be noted:

a. *Fossil Fuels:* incentive schemes for oil and gas exploration and development (various price regulation schemes are included in this category).

b. *Electricity:* rate structures of public and private utilities.

c. *Synthetic Fuels:* This is the most critical sector since it involves new technologies. The major possible investment incentive schemes include the following:

i. Price guarantees, which can take various forms:

- Fixed price level.
- Floor on return on investment
- Cost plus mark-up guarantee

ii. Direct subsidies—dollars per unit capacity or per unit output.

iii. Preferential credit—loan guarantees or low interest loans.

iv. Investment tax credits.

Demand Side:

The dynamics of demand for energy are governed by two main components:

1. Autonomous component: This results from population growth, increasing income per capita, growth in aggregate industrial output, etc.

2. Price reaction component: Given by the long-run elasticities of energy demand with respect to prices.

Much more could obviously be said about these two components. Considerable speculation has been put forth regarding the possibility of curtailing the rate of growth of energy demand by various conservation measures and the effect of higher prices for energy products. A reduced growth rate of demand for energy could result by the combined effect of three distinct spheres of impact:

1. Increased efficiency in production by energy-consuming industries using present technology.

2. Substitution of energy-intensive processes by other—presumably more capital-intensive—processes. A critical consideration here is the secondary impact on capital goods sectors.

3. Abstention by consumers of non-essential energy use—e.g., recreational operation of private vehicles.

Most attempts at quantifying the impact of reduced energy demand on general standards of living and aggregate output of the national economy, generally underestimate the autonomous component of demand growth and fail to clarify the separate effects of higher prices and indirect inducements of energy conservation. There is a growing consensus that short of a major re-examination of societal values and preferences, demand controlling measures cannot be expected to have any determining effect on the medium-term energy outlook.

V.4 IMPLICATIONS FOR POLICY MODELING

The range of potential policy instruments and the many dimensions of the policy issues have two very important implications for a modeling and policy planning program. It should be clear that no one model can describe and interrelate all the variables of interest in the energy policy arena. Therefore, the first overriding consideration for a rational policy planning program is that a number of models varying in intent and aggregation are required. Secondly, in order to construct these models with an eclectic methodological approach as described earlier, an interdisciplinary program is essential. M.I.T. has been able to achieve effective interdisciplinary interaction on the many levels of model development that are currently underway.

The next section describes and interrelates these analytical activities and briefly discusses the mechanisms that have been effective in bringing about the interaction necessary to the program.

VI. OVERVIEW OF THE M.I.T. ENERGY MODELING PROGRAM

M.I.T., under the sponsorship of the Energy Laboratory, has underway a large energy modeling and policy analysis program. The activities of modeling and policy planning group can be split into two separate but interrelated divisional functions. The first encompasses the development and application of analytical models of various sectors of the overall energy economy. These efforts vary in scope from models of the market performance of single sectors for small regions to models of the interconnection and interaction of market sectors for the entire North American Continent. This analytical base provides the substance for the second divisional activity: the study and analysis of specific energy policy and technological choices.

Modeling efforts span the range of aggregation alternatives and contain elements of both descriptive and prescriptive methodologies discussed in section IV. Some projects, by the very nature of their focus, contain more interdisciplinary interaction than others. Still, all are part of a centrally coordinated effort to work towards short and long-range solutions to energy-related problems. The major strength of the program is the scope and density of coverage that such an effort affords.

The breadth of activity is evident from a listing of the specific models and analytical tools developed. Table 1 shows such a listing. Each of these projects is listed separately because the model development in each case is under separate responsibility within the academic infrastructure. A number of schools and departments are represented in the activities of Table 1, including the Sloan School of Management, Department of Economics, Department of Ocean Engineering, Department of Electrical Engineering, Department of Mechanical Engineering and the Energy Laboratory.

Effective interchange across project lines takes place in three basic areas: through the exchange of basic data, through discussion and criticism of methodological techniques and their applicability, and finally, through the interconnection of model inputs and outputs in their actual use. Sometimes the interchange is done at the initiative of the principals involved. More often, however, the mechanism that fosters the communication is a natural fallout from seminars and/or the crossing of departmental lines by student researchers involved in the projects.

Much cross-coupling between the models is possible in terms of inputs and outputs. For example, the natural gas model requires as inputs the price trends of alternative fuels when being simulated. These, in turn, are an output of the interfuel competition model. However, the interfuel model requires a number of macroeconomic variable inputs for derivation of energy sector demands, but most of these are an output of the multisector model of the economy. We could continue with other potential model link-ups, but the relevant point is that the potential for these link-ups is an important stimulus for interproject communication.

The bulk of the M.I.T. energy modeling activity has historically centered around the development of descriptive models. It has already been pointed out that a first precondition for a truly useful policy planning model is that it be an accurate description of the real world. However, it is sometimes the case that a "prescriptive" methodology provides a most reasonable descriptive model. A good example of this is a model for electricity supply. Most utilities undertake very extensive analyses of their expansion alternatives for determination of the least cost expansion options. Sophisticated optimization tools, such as dynamic programming and mixed integer programming are used. Because of this, a reasonable starting point for a descriptive model of electricity expansion planning is the replication of the optimization techniques used by the utilities themselves. This is basically what has been done for development of the electricity supply model shown in Table 1, only the concepts have been expanded to incorporate environmental measures into the analysis. Other models listed in Table 1 have "prescriptive" structural components interconnected to form a descriptive analog of the real system.

It is also true that a large portion of modeling in the energy area, at M.I.T. and elsewhere, has centered

Table 1. Overview of MIT Energy Modeling Program

Activity	Geographical scope	Regional Aggregation	Predominant mythodology	Descriptive or Prescriptive (D or P)	Policy instruments
Natural gas supply and demand [15]	U.S.	18 FPC production districts 4 regional demands	Econometrics	D	Natural gas price
Continental oil and gas supply and transportation [16]	U.S. and Canada	60 supply nodes and demand nodes	Network analysis	D,P	Imports quota, base price of price leading region.
Multisector sector model of the economy	U.S.	National aggregated (≈ 15 sector I/0 table)	Econometrics optimal control	D,P	Prices of energy, products, taxes, subsidies
Interfuel competition model [17], [18].	U.S.	Demand by state. Supply ranges from 4 regions for coal to 18 production districts for natural gas	Econometrics, engineering analysis, system identification	D	Prices of fuels and electricity
Economic, environmental reliability trade-offs in electricity expansion planning [19]	Regional	Alternative Plant sites	Mathematical programming	D,P	Air emission standards. Water quality standards

about the market interactions of various fuels. Often this means that the predominant policy instruments incorporated into the models are fuel prices. The predominance of prices as policy instruments in the models listed in Table 1 bears this out. Nevertheless, the policy instruments actually adopted by the regulators and policy makers are usually less direct in their impact on the marketplace, taking the form of tax policies, subsidies, or other indirect inducements. These policy options often fall outside the framework of the structure of the models developed and cannot be analyzed in the rigorous mathematical framework imposed thereby. Before direct analysis of these policy options is possible utilizing the concepts established in Section V, a more thorough conceptualization of the hierarchy of the system interactions at the micro and macro level is necessary.

VII. CONCLUSIONS

Any comprehensive analysis of the future supply, demand, and price of energy must take account of competition between fuels, the effects of changing technologies, availability of resources, regulatory practices and national policy. It is against this background of complex interacting forces that computer models offer the energy planner a route to better decisions.

The range of issues and concerns is so great that no single model can possibly span them all. There are numerous energy models in existence today, and more become available as each day passes. Each model has its applications, but, because of structural rigidities imposed by a mathematical framework, each also has its limitations. Data limitations and the complexity of the problem provide ever more hurdles for the analyst to overcome. As our knowledge and understanding of the hierarchy of the system interactions advance, however, the methodological frontiers will advance to better deal with these issues.

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FOOTNOTES

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[3] We can think of U = -L as the policy maker's utility function and in this case we have implicitly assumed that U is additively separable (Heal [13], Keeney [14]. Note that the whole thrust of our approach is not to attempt to identify a unique U but rather to describe parametrically an entire family of utility functions.

[4] For our particular choice of J_1, J_2, J_3 in this example, it is implicitly assumed that there is an additional constraint to incorporate the requirement of an adequate rate of economic growth. Without this additional constraint, the minimizing solution could obviously consist of driving the economy to zero.

0 0 4 3 0 0 9 0 6

ENERGY CONSUMPTION AND FUEL CHOICE BY RESIDENTIAL AND COMMERCIAL CONSUMERS IN THE UNITED STATES

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INTRODUCTION

A number of studies have attempted to analyze the determinants of energy consumption by fuel type for natural gas, oil, and electricity[1]. By and large these studies have focused on one fuel source at a time, giving recognition to important substitution possibilities between fuels, if at all, through the inclusion of prices for one or more alternatives. Since most services requiring energy as an input can be provided with several alternative fuels[2], we believe that the possibilities for interfuel substitution must be taken into account more explicitly if econometric models are to be useful for evaluating alternative public policies. In this paper we specify and estimate a model of total energy consumption in the residential and commercial sector in the United States, and the distribution of energy consumption among the three energy sources used extensively there: gas, oil, and electricity[3].

Our conceptualization of the fuel choice decision can be summarized in the following way: the consumer decision-making process is composed of two steps. First, the consumer decides on a level of energy using services that he desires based on the price of energy, the prices of other goods and services, and household income. This decision defines the expected level of energy that will be consumed. The consumer then seeks to find a combination of fuels that will provide these sources most cheaply. Obviously, this two step procedure is not completely recursive in reality, but has strong simultaneities associated with it. However, as a "first cut" conceptualization, we believe that this is a useful way of looking at things. In any case we have built simple feedback mechanisms into our final model that we use for simulation purposes.

The paper proceeds in the following way: the first section sets up the basic model that is used for estimation. The model consists of two parts; the first is a flow adjustment model that determines total energy consumption in the residential and commercial sectors as determined by an energy price index, an index of consumer prices, and household incomes. The second part of the model consists of a set of "fuel split" equations that determine the distribution of total energy consumption among three energy sources: natural gas, oil, and electricity. A multinomial logit model is used for this purpose. Section two presents estimates of the parameters of this model based on time series-cross section data for 49 states for the period 1965-1972. The third section used these estimated relationships to make projections of total energy consumption and fuel usage for the residential and commercial sector based on five possible scenarios of the future of individual fuel prices. We find that changing relative energy prices (relative to the prices of other goods and services and relative to each other) have profound effects on the level of energy consumption and its distribution among fuels. The final section presents our conclusions.

THE MODEL

The model consists of two parts, the first a relationship for total energy consumption and the second a set of "fuel split" equations. We discuss the energy consumption equation first.

Our basic model for the demand for energy in the residential and commercial sector is a simple flow adjustment model. The desired demand for energy at time t in state i (q_{it}^*) depends upon the price of energy relative to prices of other goods and services (P_{it}) income per capita (Y_{it}) and various demographic variables (Z_{it}).

$$q_{it}^* = f(Y_{it}, Z_{it}, P_{it}, \epsilon_t) \qquad (1)$$

[ϵ_t is a random distrubance term].

But since energy consumption at a point in time depends on durable good stocks, actual consumption (q_{it}) may not be completely adjusted to desired consumption. As a result we specify the following adjustment relationship.

$$q_{it} - q_{i,t-1} = \gamma (q_{it}^* - q_{i,t-1}) \quad 0 < \gamma < 1 \qquad (2)$$

If we make desired consumption linear in the independent variables

$$q_{it}^* = \alpha_1 + \beta_1 P_{it} + \beta_2 Y_{it} + \beta_3 Z_{it} + \epsilon_t \qquad (3)$$

the final consumption relationship can be written in terms of observable variables.

$$q_{it} = \alpha_1 \gamma + \beta_1 \gamma P_{it} + \beta_2 \gamma Y_{it} + \beta_3 \gamma Z_{it} + (1-\gamma) q_{i,t-1} + \gamma \epsilon_t \qquad (4)$$

For our fuel split model we make use of the multinomial logit or "log-odds" specification[4]. That is, we explain the relative market shares of the different fuels as a function of the prices of these fuels, household

incomes and a set of demographic characteristics. Since in the residential and commercial sector we are concerned with three fuel alternatives, the basic fuel split model becomes the following:

$$\ell n \frac{S_1}{S_3} = \alpha_0 + \beta_1 P_1 + \beta_2 P_3 + \beta_3 Y + \beta_4 Z \qquad (5a)$$

$$\ell n \frac{S_2}{S_3} = \alpha_1 + \gamma_1 P_2 + \gamma_2 P_3 + \gamma_3 Y + \gamma_4 Z \qquad (5b)$$

$$\gamma_2 = \beta_2 \qquad (5c)$$

$$S_1 + S_2 + S_3 = 1 \qquad (5d)$$

where

S_i = market share of fuel i.

P_i = price of fuel i.

Y = household income.

Z = a set of demographic characteristics.

Equations (4), (5a), (5b) and (5d) make up the energy model that we seek to estimate. Equation (4) determines total energy consumption and equations (5a), (5b) and (5d) its distribution among fuels. A "feedback" from the fuel split equations to the total consumption equation is preserved since the fuel split equations determine the weights on the energy price index that appears as an explanatory variable in the total consumption equation.

VARIABLE SPECIFICATION, ESTIMATION AND EMPIRICAL RESULTS:

These relationships were estimated using a times series of data for 49 states for the period 1965-1972. The empirical specification of equation (4) is the following[5]:

$$\ell n\, q_{it} = \alpha_1 + \alpha_2 P_{it} + \alpha_3 Y_{it} + \alpha_4 N_i + (1-\gamma)\, \ell n\, q_{it-1} + \alpha_6 MT_i + \alpha_7 LT_i + \Sigma \delta_i D_i \qquad (6)$$

where[6]

q_{it} = energy consumed per capita in state i in year t.

Y_{it} = income per capita.

N_i = population density.

P_{it} = energy price index relative to consumer price index.

D_i = set of regional dummy variables.

MT_i = average temperature of warmest three months of the year.

LT_i = average temperature of coldest three months of the year

A priori we expect that α_2 will be negative and α_3 positive. The quantity $(1-\gamma)$ should be positive but less than unity and α_4 should be positive. The temperature variables are a surrogate measure for heating and air conditioning needs. One would expect that minimum temperature would be negatively related with energy consumption. The higher the minimum temperature the less the heating demand ($\alpha_7 < 0$). On the other hand, the maximum temperature variable is a surrogate measure of air conditioning needs. Since higher summer temperatures reflect a greater need for air conditioning, one would expect the sign of Maxtemp to be positive ($\alpha_6 > 0$).

In the presence of serial correlation, ordinary least squares estimation of (6) will yield inconsistent estimates because of the presence of a lagged dependent variable appearing on the right hand side of the equation. Even without serial correlation alternative stochastic specifications from the one made here would still lead to inconsistent OLS estimates. Additional problems may arise because of the use of cross-sectional data where there are differences among states. Perhaps the best way of handling this problem is to use the error components technique of Balestra and Nerlove[7]. An alternative technique for obtaining consistent estimates would be to use separate state dummy variables and an instrumental variable estimating technique. We have decided to use the latter technique here, using regional dummies instead of state dummies, primarily for reasons of simplicity.

Our estimation results for total energy consumption in the residential and commercial sectors were the following[8]: (t statistics are reported in parentheses)

$$\ell n\, q_{it} = \underset{(4.65)}{7.36(10^{-5})Y_p} - \underset{(-1.92)}{2.94(10^{-8})N} - \underset{(-1.08)}{7.89(10^{-4})LT}$$

$$\underset{(-0.65)}{-5.43(10^{-4})MT} - \underset{(-5.75)}{8.82(10^{4})P} + \underset{(7.69)}{3.97\, D_1} + \underset{(7.70)}{3.94 D_2}$$

$$+\underset{(7.74)}{3.93\, D_3} + \underset{(7.72)}{3.92\, D_4} + \underset{(7.71)}{3.95 D_5} + \underset{(27.64)}{0.78\, \ell n\, q_{it-1}} \qquad (7)$$

(t - statistics are reported in parentheses)

$R^2 = 0.94 \quad F = 603$

All of the coefficients except that for the temperature variables are highly significant and of the proper sign. The price elasticity of total demand computed from this equation is -0.74 for the mean state, but this holds only if all fuel prices increase proportionally and no fuel switching takes place. This figure therefore is an upper bound on the price elasticity before consumers are allowed to readjust their consumption bundle in response

to the new prices (we discuss this further after developing the fuel split equations more completely). The income elasticity of total energy demand is +1.00 for the mean state. From those results it can also be seen that the value of γ as defined in equation (2) is 0.22. Using this value for γ it is possible to derive a rate of adjustment for total consumption. Recall that our adjustment specification is:

$$q_{it} = q_{i,\,t-1}^{(1-\gamma)}\, q_{it}^{*\gamma}$$

where q_{it}^* is given by (3) in the previous section. If we assume for the moment q_{it}^* remains constant, then the adjustment process operates so that

$$q_{i,\,t+n} = q_{it}^{(1-\gamma)^n}\, q_{it}^{*(1-(1-\gamma)^n)} \qquad n = 1, 2, 3, \ldots$$

and as n goes to infinity q_{it+n} approaches q_{it}^*. For $\gamma = 0.22$, after five years consumption is about 65% adjusted and after ten years is about 90% adjusted. The adjustment time constant is, therefore, on the order of 5.0 years.

The short run (one year) price and income elasticities can be derived by using these adjustment parameters. After one year, the total consumption in the residential and commercial market is approximately 16% adjusted. This implies that the short run price elasticity of demand in this sector is about -0.12, while the short run income elasticity is 0.16[9].

We now turn to the fuel split relationships. The empirical specification of (5a), (5b), (5c) and (5d) is the following:

$$\ln \frac{S_g}{S_e} = a_0 + \beta_1 P_e + \beta_2 P_g + \beta_3 Y + \beta_{41} D_1 + \beta_{42} D_2 + \ldots \tag{8}$$

$$\ln \frac{S_0}{S_e} = a_1 + \gamma_1 P_e + \gamma_2 P_0 + \gamma_3 Y + \gamma_{41} D_1 \gamma_{42} D_2 + \ldots \tag{9}$$

$$\beta_1 = \gamma_1$$

$$S_0 + S_e + S_g = 1$$

where[10]:

P_g = price of gas (1972 dollars).

P_e = price of electricity (1972 dollars).

P_0 = price of oil (1972 dollars).

Y = per capita income.

D_i = regional dummies.

The estimation of the fuel split equations basically revolved around the use of OLS techniques. In all cases, since the estimated coefficients were really the result of variations in space rather than time, serial correlation of the errors was a problem. To correct for this one should allow for a different constant term for each state in the initial specification. For reasons of simplicity, we have compromised with a set of five regional dummy variables.

A much more significant and troublesome problem was the unreliability of some of the data used, to some extent with gas but even more so with the oil data. In states where only a very small amount of consumption of these fuels occurred, it was found that very high variation existed in the consumption trend over the decade. This is not surprising since the percentage error associated with any sampling process used to accumulate the data would be magnified in states with small consumption. For a state with very few supply outlets, sporadically missing a report from just one supplier, especially if large, would significantly affect the consumption trend for that fuel. Essentially, we are faced with heteroskedastic disturbances and as a result, the use of ordinary least squares without an appropriate correction would yield consistent but inefficient estimates.

If one assumes that the consumption of any fuel in a state reflects the number of individual decisions made in favor of that fuel, then the variance of the observed mean frequency (market share in our context) is proportional to the reciprocal of the number of decisions (N). To assure that the residual error terms of the estimated equations have constant variance, each observation has to be multiplied by the square root of N (in our case the square root of consumption). This weighting procedure yielded much better estimated relationships and was used throughout in the estimation of the fuel split equations[11].

The estimation results based on a time series of cross sections for 49 states over the period 1965-1972 were the following[12]: (t-statistics are in parentheses).

$$\ln \frac{S_g}{S_e} = \underset{(-11.45)}{-1.12(10^6)P_g} + \underset{(9.36)}{1.64(10^5)P_e} + \underset{(1.42)}{7.68(10^{-5})Y_p}$$

$$+\underset{(3.69)}{1.08 D_1} + \underset{(4.59)}{1.22 D_2} + \underset{(2.85)}{0.72 D_3} + \underset{(3.19)}{0.78 D_4}$$

$$+\underset{(2.78)}{0.68 D_5}$$

$$\ln \frac{S_0}{S_e} = \underset{(-2.59)}{-5.55(10^5)P_0} + \underset{(9.36)}{1.64(10^5)P_e} \underset{(-7.91)}{-5.67(10^{-4})Y_p}$$

$$+\underset{(8.38)}{3.22 D_1} + \underset{(5.56)}{2.17 D_2} + \underset{(3.34)}{1.29 D_3} \underset{(-0.53)}{-0.21 D_4} \underset{(5.32)}{-2.01 D_5}$$

$$R^2 = 0.92 \qquad F = 643.4$$

It can be seen that the price terms are all quite significant and exhibit the proper signs. The signs of the income coefficients indicate that higher per capita incomes lead to a favouring of gas over electricity and electricity over oil, all else being equal. We believe that this result emerges because gas and electricity are probably preferred fuels on the basis of cleanliness and ease of use. It is not clear, however, why this effect is more important in the gas-electricity equation. There also appear to be definite regional biases toward the fuels. Virtually all of the regional dummy variables are quite significant and the values vary markedly over the regions, especially in the oil-electricity equation. The values in the oil equation signify that all else being equal, regions 1, 2, and 5 (Northern states) are more inclined toward oil than regions 3 or 4 and the predominant supply area, region 4, is less likely to use oil than any of the other regions. In a similar fashion, the dummy variables in the gas half of the equations can be interpreted, although the variation there is not nearly so great.

From the estimated fuel split equations, the importance of prices in fuel choice decisions is apparent. Figures 4-6 illustrate the responsiveness of market shares to changing relative prices for a hypothetical state in Region 2. In each case, two of the prices are held constant while the third is varied. The plots show the equilibrium market shares as a function of price. The range of our actual price data is indicated on the axis of each plot.

The effect on the plotted results of different regional dummy variables or changed income per capita is not to change the shape of the curves, but merely to shift them left or right. The effect of changing the two prices held constant on each plot is to change the relative heights of the plotted curves. For example, if we increase the natural gas price, the effect is to reduce the natural gas market share, increase the oil market share, and increase the electricity market share. This corresponds to moving along the curves on the plots of figure 1, and shifting the curves in figures 2 and 3.

The matrix of "market share" elasticities and cross-elasticities can be computed from the estimated relationships. These are shown in Table 1. Table 1a shows the symbolic elasticities; Table 1b shows the same matrix for our estimated coefficients and mean values of the price and market share variables. The behavior of the elasticities and cross-elasticities is most enlightening. Note that they are non-linear depending both on the prices and market shares. The relationships indicate that as any given market share increases, the own price elasticity decreases and the cross-elasticities increase. This is not unreasonable, for as the market share increases, we approach the saturation shown in figures 1, 2, and 3 and the own price elasticity should decrease. At this

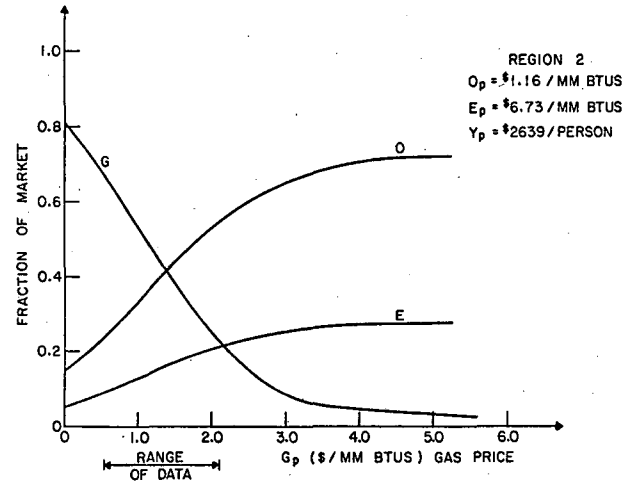

Fig. 1. Market shares vs gas price.

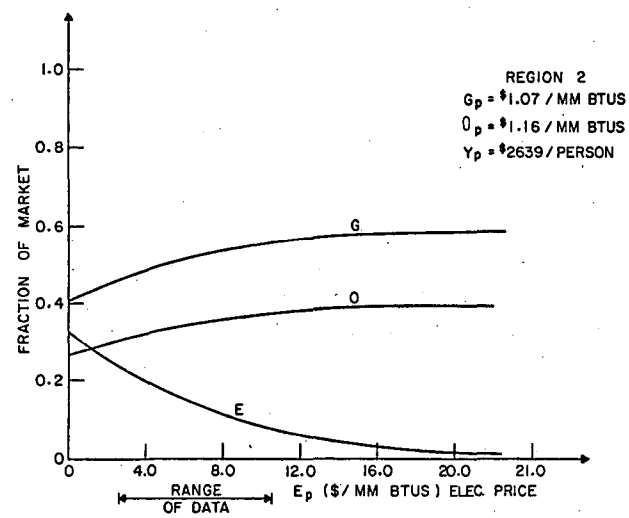

Fig. 2. Market shares vs electricity price.

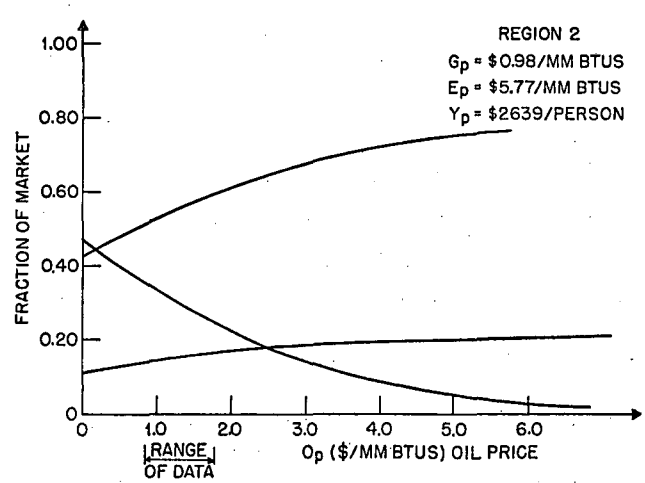

Fig. 3. Market shares vs oil price.

Table 1.

$$\ln\left(\frac{S_g}{S_e}\right) = a_{P_g} P_g + a_{P_e} P_e + \ldots$$

$$\ln\left(\frac{S_0}{S_e}\right) = a_{P_0} P_0 + a_{P_0} P_0 + \ldots$$

ELASTICITIES OF MARKET SHARES WITH RESPECT TO PRICE

	P_e	P_0	P_g
S_e	$-a_{P_e} P_e (1-S_e)$	$-a_{P_0} P_0 S_0$	$-a_{P_g} P_g S_g$
S_0	$a_{P_e} P_e S_e$	$a_{P_0} P_0 (1-S_0)$	$-a_{P_g} P_g S_g$
S_g	$a_{P_e} P_e S_e$	$-a_{P_0} P_0 S_0$	$a_{P_g} P_g (1-S_g)$

(a)

COMPUTED USING MEAN VALUES OF PRICES AND NATIONAL MARKET SHARES (1972)

	P_e	P_0	P_g
S_e	-.755	.187	.555
S_0	.194	-0.390	.555
S_g	.194	.187	-.545
	$S_e = .204$	$S_0 = .292$	$S_g = .504$
	$a_{P_e} P_e = 0.95$	$a_{P_0} P_0 = -0.64$	$a_{P_g} P_g = -1.10$

(b)

same high market share, a shift of consumption to another fuel with a low market share is a large percentage increase, consequently the high cross-elasticities. At the other extreme, as the market share approaches zero, the cross-elasticities go to zero. In this case, the impact of any shift on the market share of competing fuels is minimal.

ENERGY CONSUMPTION IN THE RESIDENTIAL AND COMMERCIAL SECTOR UNDER DIFFERENT FUTURE PRICE PATTERNS - PROJECTIONS TO 1980

We now use the estimated structural equations of our model to investigate the effects of different future fuel price patterns on total energy consumption and the use of particular fuels for the year 1980. For these simulations it was assumed that population grows at 1.4% per year and real incomes grow at 3.3% per year over the 1972 base year in each state. Then using mean values for the temperature variables, a set of simulations with the following price scenarios were performed:

- CASE I: All fuel prices remain at their 1972 values.
- CASE II: Oil prices increase by 50% to the final consumer, gas and electricity remain at their 1972 values.
- CASE III: All fuel prices increase by 50% over their 1972 values.
- CASE IV: Oil prices increase by 100%; gas and electricity prices increase by 50%.
- CASE V: Gas prices increase by 100%; oil and electricity prices increase by 50%.

All price changes are relative to the consumer price index (constant 1972 dollars) and are assumed to take place in 1973. It is further assumed that the market shares are completely adjusted in 1980. The results of the simulations for the total U.S. and four states (Massachusetts, New York, Texas and California) are summarized. For the total U.S. the summary output displayed in Table 2 clearly shows that total demand and the fuel mix is quite sensitive to the price scenario being assumed. In Case I (where 1972 prices are assumed to hold to 1980) total consumption increases by 63% between 1972 and 1980. However, in Case V (the most severe in terms of its impact on demand) the total consumption in 1980 increases by only 14% over the 1972 value. The effect of the price variations on the fuel consumption mix is quite evident.

In Case III where all fuel prices are increased by

Table 2. Simulation results for 1980, total United States ($\times 10^{15}$ Btu).

Total U.S.	1972 actual	Case I	Case II	Case III	Case IV	Case V
Gas	7.416	14.96	15.22	11.15	11.26	7.75
Oil	4.262	4.57	3.58	4.41	3.43	4.94
Electricity	2.967	4.69	4.77	3.66	3.69	3.98
Total	14.647	24.23	23.57	19.22	18.36	16.68

Case I : 1972 prices
Case II : Oil price up 50%.
Case III : All prices up 50%.
Case IV : Gas price up 50%; elec. price up 50%; Oil price up 100%.
Case V : Gas price up 100%; elec price up 50%; Oil price up 50%.

50% over their 1972 values, the 1980 consumption is reduced by about 25% below what it would be if prices remained at their 1972 values. The indicated long run price elasticity of total demand is therefore about -0.5 after fuel choice adjustments are accounted for. Cases IV and V show that an additional 50% increase in oil price or gas price over that of Case III has a very strong effect on oil and gas consumption respectively, reducing consumption of these fuels to about three fourths their value in Case III. Since such a large fraction of consumption in Case III is nautral gas, the further natural gas price increase in Case V has a much more dramatic effect on total consumption than the oil price increase in Case IV.

The output for individual states in Table 3 is also of interest. In cases where the oil price is increased beyound the norm, a significant impact on the total level of consumption and fuel mix occurs for Massachusetts and New York (large oil consuming states), but creates only a minor change in consumption of Texas and California (which consume only a very small amount of oil). The opposite is true for changes in gas price. Similar simulations could be made for all 49 states in our data set.

Table 3. Simulations results for 1980 (selected states) ($x10^{15}$ Btu)

	1972 actual	Case I	Case II	Case III	Case IV	Case V
Mass:						
Gas	0.118	0.283	0.302	0.174	0.184	0.089
Oil	0.522	0.472	0.388	0.497	0.406	0.565
Electricity	0.065	0.135	0.144	0.115	0.122	0.131
Total	0.706	0.890	0.835	0.786	0.713	0.786
N.Y.:						
Gas	0.506	1.696	1.775	1.504	1.563	1.191
Oil	0.920	0.901	0.723	0.870	0.694	0.978
Electricity	0.187	0.288	0.302	0.215	0.224	0.242
Total	1.613	2.886	2.801	2.589	2.481	2.411
Texas:						
Gas	0.343	0.722	0.722	0.522	0.522	0.353
Oil	0.030	0.016	0.011	0.012	0.008	0.012
Electricity	0.214	0.245	0.245	0.181	0.181	0.186
Total	0.587	0.982	0.978	0.716	0.711	0.552
Calif.:						
Gas	0.913	1.38	1.384	1.027	1.027	0.711
Oil	0.028	0.030	0.023	0.026	0.019	0.027
Electricity	0.297	0.449	0.449	0.339	0.339	0.353
Total	1.237	1.861	1.856	1.392	1.386	1.103

CONCLUSION

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

The model used to explain total demand for energy in the residential and commercial sector is a simple flow adjustment model. The long run price and income elasticities of demand in this sector were estimated to be about -0.50 and 1.0 respectively. The short run (one-year) elasticities were about 16% of these values.

Finally, a set of simulations to 1980 were performed using some hypothesized price scenarios. The results show that much conservation can be expected to take place in the residential and commercial sector as a result of price increases and that the geographic shifts in consumption are highly dependent on both the particular fuel in use and the cost of competing fuels in the region. Both these effects should have important significance for policy decisions in the energy area.

APPENDIX A

DATA SOURCES AND DERIVATION

The data series used for this sector run generally from 1965-1972 be state, i.e. 48 states and D.C., though occasionally, observations on states are by necessity combined. Specifically, there is no gas consumption in Maine and Vermont until 1966, and even then their consumption and price data is combined with that of New Hampshire. In addition, both gas and electricity data for Maryland and the District of Columbia are always combined. Thus, because of the structure of the estimating equations, the total energy demand equation and the gas half of the fuel choice equation observations for Maine, Vermont, and New Hampshire are combined, as are observations for Maryland and the District of Columbia; in oil half of the fuel choice equation only observations for Maryland and District of Columbia are combined.

The price data (which is at the retail level) is in

$/BTU; the consumption data is in BTU's; the surrogate capital cost data is in $/unit; income per capita is in $/person, and all other variables are in similar singular units.

All variables involving dollar figures have been adjusted by the cross-sectional time-series deflator later described.

NATURAL GAS

Natural Gas Price and consumption data is clearly the most reliable, structurally, of our observations in the residential-commercial sector. The Bureau of Mines (Minerals Yearbook) provides information on sales and revenues by year by state for both the residential and commercial sectors. The sales data, in MCF's, is converted to BTU's by the state conversion factors for electric utilities' fuels consumption found in the Edison Electric Institute's Statistical Yearbook. The prices result from dividing revenues by sales, and the price for the residential and commercial sector is an average of the prices weighted by each sector's consumption.

ELECTRICITY

Electricity price and consumption data is readily derived from the Edison Electric Institute's "Statistical Yearbook's" Sales and Revenues sections. The data is available for the residential sector specifically, but not for the commercial sector. We have had to assume that the small light and power figures are roughly proportional to what would be actual commercial sector figures, since no data source separates "commercial" from industrial, but rather, only "small light and power" from "large light and power". The consumption data is converted to BTU's by 3412.8 BTU's/kwh, and the price data, like that of gas, is an average of the residential and small light and power prices weighted by each of these sector's consumption.

OIL

Oil data is by far the most unreliable of the three energy data sets. If one looks at 13 years of distillate and residual heating oil consumption for particular states, the series suspiciously cycles. This comsumption data is found in the Bureau of Mines' Mineral Industry Surveys, "Shipments of Fuel Oil and Kerosine (kerosine used for heating is not included in our analysis), broken down by distillate grades one through four and residual grades five and six. A representative of this publication claims that heating oil used industrially is not consistently included or excluded form the heating oil figures from year to year; so, it is not even possible to explain this noise with a level-of-economic activity regressor.

None of this data is broken down by sector, i.e. residential or commercial or industrial heating use - it is assumed that numbers 1 through 6 distillate and residual heating oil at least exhaust residential and commercial uses of oil substitutable with natural gas and electricity, and is roughly proportional to what would be the actual consumption in these sectors. The raw data, in barrels, is converted by 5.825×10^6 BTU's per barrel of distillate and by 6.287×10^6 BTU's per barrel of residual.

The only retail oil price found on the state level is for # 2 fuel oil. This data was obtained from the American Gas Association. We are well aware of this regressor's unreliability as a distillate-residual oil price in the residential -commercial sector (though it is probably a reasonable surrogate for a distillate oil price in these sectors), but there is nothing more available.

MISCELLANEOUS

The temperature variables used here are the average temperature of the three warmest months and the average temperature of the three coldest months in degrees Farhrenheit. This information is from the Department of Commerce's National Oceanic and Atmospheric Admimistration publications.

The adjustor used for all dollar figure variables is a time-series, cross-sectional deflator constructed through the work of Kent Anderson for 1970. This 48 state deflator (Maryland and District of Columbia combined) is adapted to 1960 through 1972 by the nation wide consumer price index. This, of course, very strongly assumes that the inflation rates are uniform all over the United States, i.e. that the relative cost of living in each state does not change over time. It is thought that this procedure is no worse than obtaining the cost-of-living studies done by the Bureau of Labor Statistics for three of the thirteen years in question and extrapolating and interpolating the other ten years, expecially since this cost of living index is not available by state. Since our research employs cross-sectional time series data and since there is not enough variation in price or any explanatory variable over time to fit a demand curve, it was assumed that a deflator oriented primarily to cross-sectional variation would suffice.

The Anderson index for 1970 is constructed as follows:

> "The 1970 B.L.S. data for SMSA's on the relative living cost of a family of four having an "intermediate" budget permitted construction of an index for state metropolitan areas. Indices for state non-metropolitan areas were set at 90/103 of the metropolitan indices, based upon the U.S. averages for these two types of areas[13]".

Every effort has been made to obtain the best data available—any suggestions as to better sources of data series would be greatly appreciated.

APPENDIX B

Table B-1 Regions for dummy variables.

I	II	III	IV	V
ME	PA		COL	
NH	OH		NEB	
VT	IND	VA	KAN	MONT
MA	ILL	KEN	TENN	
RI	MICH		ALA	ID
CONN	WIS	WV	MISS	
NY	MINN	NC	ARK	WYO
NJ	IO	SC	LA	UTAH
DEL	MO		OKLA	
MD	END	GA	TEX	WASH
DC	SD	FLA	NM	
			ARI	
			NEV	
			CAL	

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FOOTNOTES

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[1] Fisher and Kaysen, Anderson, Halvorsen, Balestra, Houthakker, and Taylor are all excellent examples.

[2] See Baughman and Joskow (5).

[3] See "Patterns of Energy Consumption in the United States", Stanford Research Institute, January 1972.

[4] This specification is based on a theory of individual fuel choice behavior that has been presented elsewhere. See Baughman and Joskow (5), and Joskow and Mishkin (10).

[5] We have experimented with a number of specifications of equations (1) and (2). The specification which gave us the best statistical results was:

$$(1^1) \quad \ln q_{it}^* = \alpha_1 + \beta_1 P_{it} + \beta_2 Y_{it} + \beta_3 Z_{it} + \epsilon_t$$

$$(2^1) \quad q_{it} = q_{i,t-1}^{(1-\gamma)} q_{it}^{*\gamma}$$

We report the results for this specification in the text and those for the simple linear specification in a footnote below.

[6] The data are discussed in Appendix A. The regions are defined in Appendix B.

[7] See Balestra and Nerlove.

[8] The results for the simple linear specification are:

$$q_{it} = 3.98(10^3)\,Y_p - 0.219\,N + 6.98\,(10^3)\,LT - 3.52(10^4)\,MT$$
(2.80) (-1.48) (0.10) (-0.44)

$$-\,3.82(10^{12})\,P + 1.00(10^7)\,D_1 + 8.53(10^6)\,D_2 + 8.33(10^6)\,D_3$$
(-3.04) (1.32) (1.08) (1,06)

$$+7.61(10^6)\,D_4 + 9.02(10^6)\,D_5 + 0.88\,q_{it-1}$$
(0.96) (1.22) (33.6)

$R^2 = 0.90$ $F = 350$

Note that both temperature variables are insignificant and have the wrong sign.

[9] We have also estimated (7) without the regional dummy variables with the following results:

$$\ln q_{it} = 6.92(10^{-5})\,Y_p - 3.25(10^{-9})\,N - 7.92(10^{-4})\,LT - 1.35(10^{-3})\,MT$$
(4.42) (-2.41) (-1.36) (-1.80)

$$-\,7.58(10^4)\,P + 0.82\,q_{it-1} + 3.32$$
(-5.42) (33.7) (7.34)

$R^2 = .94$ $F = 995$

The only significant differences between this equation and that given previously with regional dummy variables is the size of the maximum temperature coefficient and the value of γ, the adjustment coefficient. In this equation the maximum temperature variable picks up the variation attributed to the regional dummies of equation (7), and the value of γ yields a slightly slower rate of adjustment.

[10] The data are discussed in Appendix A.

[11] See Theil (1972) pp. 174-177 and Theil (1971) pp. 631-633.

[12] Originally, these equations were estimated using data on costs of a standard size furnace. Later, we learned this was very unreliable data constructed for 10 years and 49 states from a very small number of actual observations. The costs of furnaces were then dropped from the estimation procedures. Before eliminating the capital cost numbers, the estimation yielded.

$$\ln\left(\frac{S_g}{S_e}\right) = -1.25\times10^6\,P_g + 2.30\times10^5\,P_e - 0.00908\,G_{cap} + 3.42$$
(-18.9) (24.9) (-11.9) (15.2)

$$\ln\left(\frac{S_o}{S_e}\right) = -3.78\times10^6\,P_o + 2.30\times10^5\,P_e - 0.00608\,O_{cap} + 6.07$$
(-13,0) (24.9) (-5.6) (21.1)

$R^2 = .96$ $F = 4674$

where G_{cap} is the cost of a gas furnace.

O_{cap} is the cost of an oil furnace.

It is unfortunate that the data were not more reliable because these results do look quite good.

The equation was also estimated using time dummies in place of the constant, a different one for each year of the data. The results were very stable as the constant varied only a few percent over the decade.

Finally, the equations were estimated using temperature variables instead of regional dummies.

$$\log\left(\frac{S_g}{S_e}\right) = 9.77\times10^5\,P_g + 2.52\times10^5\,P_e$$
$$-2.72\times10^{-4}\,Y_p - 0.00425\,\text{Maxtemp}$$
(-12.3) (16.8) (5.75) (-1.59)

$$-0.00618\,\text{Mintemp} + 0.357$$
(2.96) (1.01)

$$\log\left(\frac{S_o}{S_e}\right) = 4.31\times10^6\,P_o + 2.52\times10^5\,P_e$$
$$-1.27\times10^{-4}\,Y_p - 0.0103\,\text{Maxtemp}$$
(14.7) (16.8) (-1.7) (-4.66)

$$-0.02137\,\text{Mintemp} + 6.08$$
(-5.63) (10.9)

$R^2 = 0.85$ NOB = 980 $F = 587.8$

These results show that the higher the temperature, the more electricity is favored, as expected. These results look quite good; however, when regional dummy variables were used the temperature variables became insignificant. Due to the collinearity with the regional dummies, the temperature variables were dropped from the estimation procedures.

[13] Residential Energy Use: An Econometric Analysis (prepared for N.S.F.), October, 1973, Kent P. Anderson, pp. 21-22.

SUMMARY OF DISCUSSION

To estimate the market share of oil with respect to electricity, the price of a third fuel (for example, gas) need not be included in the estimation equation. This is an application of the assumption of the independence of irrelevant alternatives. Regressions were run with the third price term included to test this assumption; the resulting coefficients appear to be much smaller, confirming the validity of the assumption.

The model does not account for the dynamics of change in the short run; it assumes a long run equilibrium. This assumption was verified by checking the stability of parameters over time. The period 1960-1970 was divided in half and the parameters were estimated for both periods. The parameters came out within 5% of each other, which supports the assumption.

Fuel choice often is not made by the consumer, nor is it based on price. Rather it is made either on the basis of nonavailability of certain fuels or on the basis of cost considerations on the part of building contractors. This phenomenon is not built into the model. To correct for this, it was suggested that the states where fuel shortages exist should be dropped from the sample. Baughman tried to adjust for this by constructing dummy variables for those states and by grouping them to minimize this influence on the elasticity estimates. Since only the intercepts were dummied, the slopes can still be biased.

The question was raised as to the appropriate role, if any, for behavioral psychologists and other social scientists in the quantitative analysis of supply and demand. Survey work was mentioned as one method for introducing data from other social science disiplines. This appears to be a major undertaking that has not yet been attempted. Moreover, at this point there does not appear to be a good predictive theoretical framework that would incorporate the data obtained. An attempt to incorporate aesthetic factors into the estimation of the demand function for solar energy was mentioned as an example of possible work in this direction.

The question of utilizing other behavioral sciences for estimating demand functions bears directly on the question of how valuable and how accurate is the concept of elasticity, inasmuch as this concept embodies changes in consumer behavior and lifestyle resulting from price changes. Elasticity is an inherently dynamic phenomenon which depends upon the length of the time period under examination. While recent studies show that estimates of long term elasticities fall within a well defined (though broad) band, there are still methodological problems, for example with multicolinearity.

The problem of using these descriptive models for normative analysis by decision makers was discussed. This entails constructing a meaningful set of objective functions, which is difficult for two reasons. First, it is not clear how to form a good probabilistic utility function. Second, positing a reasonable objective function from a societal point of view probably does not reflect the objective function which best describes the way policy makers behave. For example, the Federal Power Commissioners may try to minimize the political friction they encounter. This is not coincident with an appropriate objective function from a consumer's viewpoint. It was pointed out that constraints in optimization models may represent the behavior of, for example, capitalists or environmentalists. But it is not clear what behavior is being described.

One solution to the problem of constructing a reasonable objective function is to posit a series of objective functions and point out what constitutes a set of optimal policies. However, the objective functions are not appropriate if they fail to reflect what policy makers think are important objectives. This leads to the question of who are the policy makers. It appears that very little research has been done on this topic.

There is a gap between model builders and policy makers which may result from 1) dissimilar backgrounds and training, 2) the dynamics of organizational behavior, 3) lack of awareness by model builders of the problems policy makers face, and 4) lack of understanding of the models by policy makers. One example of good rapport is the relationship between monetary economists and the Federal Reserve Board. Because the art of energy modeling is much newer, energy problems have not been adequately anticipated. With time, confidence might develop in the models and a closer relationship between modelers and policy makers might follow.

People who fund modeling do not necessarily make policy. This is a partial cause of the gap. It was suggested that decisions are made not by policy makers but by referees who decide between alternative proposed policies. Because of the time lags inherent in research and subsequent publication, the usefulness of models depends partly upon how well model builders anticipate problems that policy makers may not recognize, and how well they then bring them to public attention before the crisis situation sets in. The experience of many people in the oil industry indicates that this is very difficult. Long term policy questions are often answered using the results from research designed to answer short term crisis situations. The usefulness of models also depends upon the degree to which policy makers feel the model sensibly describes the current situation and recent history. Acceptance of models depends upon their conformity to policy makers' preconceptions.

DISCUSSION

GRIFFIN: Marty, I have two questions. First, I was looking at these market share equations, and I'm bothered by the fact that when you explain the share of oil with respect to electricity, the price of gas does not appear in that equation. Now, if you start from a utility function or an indirect utility function focusing on prices, presumably the price of oil or prices of all of these energy forms should affect the choice between oil and electricity. Have you run these equations including the additional price term and found it not significant?

BAUGHMAN: The price does feed into the market shares of all the fuels. The third equation says that the sum of these market shares must add up to one.

GRIFFIN: Exactly. But the share of oil vs electricity should in principle also be affected by the price of gas.

BAUGHMAN: Well, there is an assumption that is built into this that I was mentioning yesterday. The assumption is that the price of gas does not affect the ratio between oil and electricity. You are questioning that assumption.

We have run some regressions including the price of the third fuel, and it doesn't appear to be nearly as important as do the two prices under consideration. It was only marginally significant with a much smaller coefficient. Obviously, in the extreme, one wouldn't expect the price of the third fuel to effect the ratio of the two that are represented on the left-hand side. For example, if the price of gas is $10/million BTU's and the price of oil and electricity are somewhat smaller and comparable, then there is no reason why the price of gas should have any effect on the ratio of oil to electricity. So it is a property in the extreme that isn't hard to justify. We've dropped it out of the estimated relationships.

HOFFMAN: May I add one point? For electricity, the price of gas would operate because of the use of gas in the generation of electricity. It's a minor factor and it's less important.

BAUGHMAN: There are problems with the particular work that was done here. One of them is that the price of electricity is not independent of the price of oil and gas, that's for sure. Another one is that we have not really taken into account the dynamics of change. Basically we have assumed that we are on a long run equilibrium, at least cross-sectionally, on the data base, and currently that doesn't seem to be too bad an assumption. We broke our decade up into 1960-65, and 1966 to 1970, and we estimated the equations. The parameters came out to within 5 percent of one another. Secondly, if we really want to use the theory for individual fuel choice decisions, what we should be measuring with our price is dollar per effective BTU into a house, taking into account the difference in efficiency of converting electricity to heat and oil and gas to heat. Now, if that were the case, if we had those data, the theory says that the coefficients of all these price terms ought to be exactly the same. Because we couldn't get that kind of information, we relaxed some of the purist assumptions here, allowed the price coefficient to be different, and went ahead and estimated it. We did that mainly because we liked the saturation-type property that the equations have.

McCALL: It seems to me that your argument is that if you pick a region, you will only find two prices that are close and the other one is priced some distance away.

BAUGHMAN: No, no, you can have three or more. In the industrial sections you can have four fuels that are competitive, and each of their prices would enter into the equation where that fuel appears in the left-hand side. When you go through the actual computation of the market shares, all the prices enter in. Now, in some cases, one may be priced way out of the market and then its market share would lie on the extremity of the curve. We also have data points in the extremes; we have cross sections in our sample where essentially no gas is being used and others where no oil is being used.

McCALL: The decision-maker on home heating technology is usually not the consumer. Would you care to comment on that?

BAUGHMAN: We have tried to accumulate some data on what the initial cost of installation of some of these alternatives is. In fact the report here footnotes some results where we incorporated some data on costs. It really came out quite well, but we had a heck of a time finding good data on costs of installation of gas furnaces, oil furnaces, and electric heating insulation, so we dropped it out. Ideally, that should be included and maybe in some interactive way, so that you also estimate a discount rate to capture how important the capital cost is. Depending upon who was making the decision, the discount rate would either be zero or it would be infinity . . . or anywhere in between.

VERLEGER: Quite frequently, it is not the cost of the

capital that is the controlling factor but it is the speculative builder. How much is he going to get from different organizations, or, more critically now for the last few years, will he get fuel at all? That worries me in estimating the share equations, because, especially in your cross-sectional sample in 1969, there were some regions in the country where residences weren't able to get fuel, particularly natural gas. Somehow, if you can include that in your distribution, it will change the parameters away from what you are calling your equilibrium model.

BAUGHMAN: In fact, we had that experience. Of course, the other things that we really need to link this up with are supply models for simultaneous estimation. We first estimated using the 1960 to 1969 data; we estimated again using the 1965-1973 data. The coefficients changed, but they changed in such a way that the explanation you gave of a shortage of gas was a plausible one. In fact, we did some simulations here using our 1960-1969 data base, and we overestimated gas consumption.

VERLEGER: It would seem to me that the really correct econometric approach to attacking that problem would be to omit from the sample those states where you know there are natural gas shortages.

BAUGHMAN: Yes. We constructed dummy variables for those states, based on information from MacAvoy, Pindyke and grouped them together so they didn't influence the elasticity.

GRIFFIN: Did you just dummy out the intercepts?

BAUGHMAN: Yes.

GRIFFIN: I think you should be aware they can still bias the slopes.

VERLEGER: You should be estimating with two sets of samples where you allow for the whole set of parameters to be different.

McCALL: I had another thing I wanted to mention. I'm just simply not aware how many people have seen this. The National Electrical Reliability Council published a study of the future requirements for fossil fuels. It came out of all the member organizations. It's on a pre-embargo basis, but it might be of interest for model testing. This, in effect, is an aggregated utility company expectation for both installed capacity (to determine the type of generating equipment), and for the effect of load duration curves (because they publish fuel used in connection with capacity).

KAUFMAN: I wanted to go back to Marty's point about doing normative vs. descriptive analysis, and assert that we really should not under-estimate the enormous analytical difficulties in doing coherent normative analysis with models of the types that we have been talking about. There have been very few attempts that I have seen to do this. I have a former student who is at the University of Pittsburgh and who is presently working with the Pindyke-McAvoy model attempting to put this into an optimal contral framework. In order to do so, one has to posit some kind of meaningful objective function. It certainly can't be a linear one. In addition to not being linear, it is clear that, from the point of view of the Federal Power Commissioners, they are looking at a problem in which the consequences are multi-attributed and incommeasurate. For example, one can begin to look at price as a numerare, excess demand as a numerare, and additions to reserves as a numerare. These are clearly three quite different kinds of beasts. To get the kind of tradeoffs that Marty is looking at is an extremely difficult task. There are two reasons. First, it is not at all clear *a priori* how you form something like a good probabilistic utility function. Second, positing what from a societal point of view constitutes a reasonable objective function (in capturing the nature of risk and enabling you to make the tradeoffs and make incommeasurables commeasurable) probably doesn't reflect at all the way the FPC commissioners behave. They like to keep case load low and to minimize political friction. That is not necessarily in coincidence with what we would regard as an appropriate normative analysis. We haven't discussed these points very much here, but I think it would be interesting to get some insight into what people have to say about these issues. To what extent can the kind of descriptive models we've been talking about be pushed in this normative way?

BAUGHMAN: I didn't mean to imply that I thought it was easy, but I think there are many things one can do. For example, take every component of your objective function and set up optimal control feedbacks that are multivariable, where you have policy instruments that you may want to move around (such as tax subsidies, depletion allowances, prices and so forth). It would even be interesting to set up a linear construction of these objectives and weigh each one of them individually. First you have just one objective in there at a time; then use the optimal control feedback ideas to try to define which policies are best to reach that particular objective. Then, of course you can weight them in and group them one or two or three at a time and see what mix of policy instruments is best suited for that particular objective. I don't think as analysts we can view our role as trying to define what the weighting

should be on these objectives, but we should do it for a whole range of weightings.

KAUFMAN: You can do a conditional normative anlysis by positing some kind of objective function and then another one, and then another one, and pointing out what constitutes a set of optimal policies. But it seems to me that the design of the models we want to use to help policy makers somehow has to reflect what they think is important in terms of objectives. In all of the discussion I have heard about policy models over the past year or two, very little attention has been paid to doing some hard core descriptive work on what the people who use these policy machines for analyzing policy really think is important and what their objective function ought to look like. There is just no research that I am aware of that's really being pushed in this area.

HOFFMAN: It seems that in meetings like this people always talk about the decision makers and try to identify who they are, but I haven't met anyone yet who knows a decision maker.

KAUFMAN: Well, I think in the gas situation you can talk about the Federal Power Commission. Now it certainly must be true in other areas, if you think about it hard enough you can figure out who these people are.

HOFFMAN: What role does quantitative analysis play in their decision making?

SMITH: As a former member of the Federal Power Commission staff, I think I can comment. You are right about trying to determine what the numerare is. Of course, there are five commissioners and that means that there are at least five different opinions depending on whom you are talking to. I think the macro-type models are the ones they are really paying attention to.

HOFFMAN: Is that because it matches their preconceived notions or because it fits in with what they have already decided?

KAUFMAN: Bruce, is it being unfair to say that there is a substantial gap between what people external to the Federal Power Commission would view as kind of the rational normative objective function and what the Commission actually does, such as minimizing case load and making sure they don't upset Congress, which is a lot more important than considering tradeoffs between excess demands and the effective price on the consumer, and so on?

SMITH: Yes. I think that's right. Of course, over the last couple of years the Commissioners on the gas issue have de-facto allowed de-regulation for all of the redundant sales. This is, I guess, in one sense a case of minimization. But in another sense it is their personal feeling that by minimizing the regular premium tacked-on price these supplies will be forthcoming.

VERLEGER: How do you fit within that framework the decision last week to set the US area rate at 42 cents per thousand cubic feet? That seems to be well below the market clearing price at the present time.

SMITH: First they did it on a company-by-company basis because of the area rates, but now, of course, they have decided to go to a national rate. It depends on what area you are talking about because in some areas 42 cents is probably a bargain. Here I am going to talk about cost and market clearing prices.

VERLEGER: Okay, I was going to say that the areas we will be thinking about would be something like Permian Basin in Texas although the intra-state contracts down there are now at one dollar or above per thousand cubic feet.

HOFFMAN: What intrigues me about your methodology is the ability to incorporate consumer behavior and policy behavior into this type of framework. I'd like to explore two questions. First, to what extent have you tried to bring in behavioral psychologists and non-economic social scientists to quantify some of these parameters? It seems to me that you've turned more toward the econometric estimation parameters. Have you tried the other route? Second, is there a role for behavioral psychologists and social scientists in the quantitative analysis of energy supply and demand?

Let me introduce one more point. I have heard it argued that we would have been better off if this notion of elasticity had never been invented. The first reaction of scientists and engineers when they learn about elasticity is to say, gee, that's a beautiful neat concept. It explains lots of things, so let's go out and design experiments, measure them and publish them in handbooks like neutron cross sections. Later, you learn that these are very transitory things. They cover up many unknowns. You get into problems in econometric estimations. You get excellent fits between totally unrelated causal parameters. So let me make the case that the notion of elasticities and their use in these models has retarded deeper investigation into the causal factors behind the trends and facts we are trying to study.

BAUGHMAN: Well, in a sense I agree with you. I think we have to recognize that elasticity is basically a static concept, in fact a linearized concept.

HOFFMAN: Yes, but it need not be. In principle, it can be non-linear, and it can include lag effects.

BAUGHMAN: You have to be very concerned about those effects when you are talking about elasticity, when you talk about a response to changes in price.

HOFFMAN: They are representations of individual behavior with changes in life-styles and values and alternatives.

BAUGHMAN: I think that goes back to your first point. We have considered, for example, survey work and things of that sort to try to bring some of the behavioral sciences into the estimation of parameters. We haven't been successful at this point.

HOFFMAN: Is it a lack of interest on their part, or are they too busy doing their own research?

BAUGHMAN: Well, we have had discussions with people in political science, and it seems like there is a desire, but . . .

HOFFMAN: Senior people or young people? I would think that senior people would be reluctant to get involved.

BAUGHMAN: Yes, there were senior people, but the difficulty, I guess, is that once you do it, it has to be very scientifically done. It is a big job. Given the amounts of available data that we have, I think that there is much to be done to the specifications of the models using that existing data base. That's not to say that this wouldn't be worthwhile doing. I would suggest that you mention to Tom Sparrow that he get something started along that vein.

HOFFMAN: I'm not saying that we should overturn the use of elasticity. It happens to be the best technique we have now. But we should try to go a step further, I think.

VERLEGER: I'm really sort of disturbed by your remark, probably because I have a vested interest. For one thing I think that we throw around the concept of elasticities without recognizing that is an inherently dynamic phenomenon. There are the short run, one year, two year, n-year period responses. I was looking at results for electricity, and we are now beginning to see a set of estimates fall within a band. We can't, obviously, go out on a limb and say that the true long-term elasticity of demand in the industrial sector, say, is one, but we are beginning to see a band that ranges anywhere from 0.5 up to 1.4. We are, in other words, narrowing it down. I think this is an essential point.

HOFFMAN: How sure can you be of that? Could it be 0.2 or 4?

VERLEGER: Well, we've done studies using different samples and different approaches. Still we are beginning to get some confidence in our results.

HOFFMAN: How about collinearity problems? Methodologically, can those be overcome?

VERLEGER: Multi-collinearity is a problem that shows up when you get non-significant price terms.

HOFFMAN: Well, what is the term when you get a good fit for the parameters that are obviously totally unrelated?

KAUFMAN: Spurious correlation.

VERLEGER: The whole point is that the reason economics has a predictive power is that, based upon this optimization notion, prices really do matter. If you are going to replace this optimization notion by saying that somehow people are guided by certain non-economic rationales, then you have to provide another theory that predicts as well. Now, I think that's great if we can get another theory, but I haven't seen it yet.

HOFFMAN: I'm all for optimization, but . . . I notice in your remarks that, when you talk about building a better model for the utility sector, you talk about building in optimization. Dick has outlined some of the problems, such as regulatory and financial problems . . . But we have got to get a better handle on what we mean when we apply these constraints, and how they represent the behavior of environmentalists or capital markets.

BENENSON: Ken, regarding your first suggestion, we proposed to do someting like that, incorporating psychological analysis into the demand function. We are trying to estimate the demand for solar energy, and in this particular case the devices are visible so they have aesthetic impact. We are trying to measure this impact, using a group of psychologists who question people about a film that simulated a drive through a solar city. There is an environmental simulator on the Berkeley campus. One can put a photographic probe in the model of a city or suburb which has solar collectors on the rooftops. The photographic probe is used to take snapshots of the model, which is then translated into a 35 mm movie. It's quite realistic. Viewers of the movie are questioned. Another group of people are driven through the actual area from which the model was made. These people are also questioned to serve as a control for the experiment. This is recorded and incorporated into an econometric

model. Unfortunately, the project was not funded.

SPARROW: On the demand side, taste is what runs things, and that's in the demain of the psychologist, but on the supply side, technology runs things and that's the domain of the engineer. Yet when you get an economist working with an engineer and a psychologist, he acts as if the whole world was laid before him and he himself is the proper man to reveal all of these mysteries.

BENENSON: Have you ever worked with physicists?

HOFFMAN: Not being an economist but a technologist, I can say certain things about the supply side. I can talk about an LMFBR or an electric car or things like that with great confidence, but I don't have the foggiest notion what the likelihood is of these things being accepted and marketable. I think that is the economist's bag.

Back in the late forties the engineers talked about electricity which would be too cheap to meter. I don't think the economists ever believed that, and they turned out to be correct. If the technologist has a very sophisticated novel supply technology, the economist looks back at the history of these things and knows that it very seldom works out that way. They can't go very far wrong when they take a less optimistic view than the technologist. I think they are stabilizing; my contact with them is stabilizing.

BREEN: May I go back with regard to who the policy makers or the decision makers are? Then maybe we can look at the policy makers at the federal level such as the FPC and at the local level such as our state regulators. Then perhaps look at ourselves as model makers or analysts. That there is a tremendous gulf between the analyst and the policy maker is not hard to recognize, and maybe some of our attention should be directed more toward this idea, too. Consider the idea of elasticities. Here in California, for instance, economists have spent a lot of time selling the idea that the price elasticity of demand is an important concept. Now California Public Utilities Commission is very much interested in this concept. They are facing problems that they haven't had to face in the past. Mostly they are engineers with little or no training in the social sciences or economics. We've been such good salesmen in selling our idea (whether a good idea or bad idea is not important) that it is now a policy tool or policy instrument that is probably going to be used. I think what this brings out in my mind is that we should first of all be more careful deciding what ideas we want to sell to the policy maker (once we identify who this policy maker is) and, secondly, we should do a better job of selling the idea of taking a quantitative approach.

We should not just discuss internally different approaches that are available for decision making, the quantitative tools available, but present the tools to those who would make use of them in decision making. This goes also for the corporate management, too. The education there has not been very good. So we have working on one side the planners and analysts, sort of incestuously trading ideas back and forth, and on the other side we have these not-so-easily-identified decision makers. Somehow we should bridge this communication gap a little bit.

KAUFMAN: Well, there is a sociological problem that most of us are very unwilling to face, because we all like to retreat into our own domain of expertise when faced with a difficult problem. That's true on both sides of the fence. The dynamics of organizational behavior in the face of rapidly changing decision-making technology is something that is not very well understood at all. In many cases of consulting and attempting to bring these policy tools into play, we find that the people in these organizations regard us as overt threats to their personal role in an organization. To my way of thinking this is severe methodological difficulty. It is methodological because we are dealing with human behavior in trying to interface these things with decision makers. The fact that we are dealing with human behavior means that somehow the methodology itself (the analysis, the policy tools, and the way the output is shaped) has to take cognizance of this fact. I have seen very little research on this, and it is really a pity because we're all going to end up working for our own applause and nobody else's unless we pay a good deal of attention to this. The only hope is that as the generations change, these ideas that we're selling will be so carefully woven into the intellectual fabric of the people who move up in the organizations that they will be easy to accept. But in the interim, we are faced with a very troubling set of issues.

VERLEGER: If we go back to your initial point of how to influence policymakers, we ought to take as a prototype the way the monetary economists have managed to begin working with bankers and with the Federal Reserve Board. It would appear that the MIT-FRB-PENN-econometric model has had some influence on monetary policy over the last two years. Now some of the forecasting economists are beginning to wonder whether it has had too much influence in the last six months! But the fact is that it is one case where modeling has begun to be integrated. In fact bankers, who historically have had very little use for economists, are beginning to listen to them, and economists are moving up through the organizations. I guess Arthur Burns

has reached the very pinnacle of the organization, and the system may function marginally better.

KAUFMAN: What can you distill from that experience?

VERLEGER: I think one of the things you can distill is this cooperation between model builders and model users.

BREEN: But isn't this because of the rather unique institutional structure that we have with the Federal Reserve, which is there to fund the research and bring together bankers and economists in one place, whereas in the energy fields you don' have such . . .

VERLEGER: Now we have the Federal Energy Agency and NSF. I think that it became clear that the economists started asking the bankers what they needed to forecast. If you look at the original Kline-Goldberger model, there is a very minimal monetary sector and it was almost useless to forecasting. But if you now look at the Penn-FRB model, they deal with the term structure of a number of interest rates, and they have listened and talked with bankers to find out how the relationships between the interest rates are determined. It is this interaction between the bond traders, the bankers, and the economists which is good. I think the other thing we have to recognize is that the energy modeling and energy policy modeling is really a relatively new field, two or three years old at best. And I think that with time, confidence will develop in some of these models. There is on the part of policy makers, and I think justifiably so, a concern with just about any model they can pick from. Macro-economic modeling is a much older field, and it takes time to get these ideas accepted within the institutional and political framework. I think it will happen.

GRIFFIN: We are probably just now at the stage of the Kline-Goldberger model. Maybe not even that far. We're probably about 20 years behind.

VERLEGER: You know, the European countries are interesting in terms of economic planning. They are ten years behind the United States in trying to specialize the planning models and forecasting models to the point where planners will use them. I think it's the same point you were making that you need more cooperation between technologists and psychologists and also with decision makers in terms of thinking about the question "What is needed?"

KAUFMAN: Well, there are two facets to it. You need that cooperation, but we don' really understand very clearly what the dynamics of that interaction ought to be. It is a muddy area that falls at the interface between organizational behavior concerned with the introduction of innovation, and decision making techniques and a rapidly changing technological environment. In the modeling, I think all of us have given up.

SPARROW: The reason modelers do modeling is because that's what they like to do, and the reason policy people do policy work is because they like to do it. There is nothing more discouraging in R and D funding than to have Mr. X call us up and say: I have a great idea. I am going to convert the 365 matrix from dollars to BTU, and the reason is because we in state X need it desperately. I say, "That's already been done", the guy says "oh". And he never contacts me again. The reason is that he is interested in the research, not the utilization of it. That is just a fact of life. Researchers want to do research, policy makers want to do policy-making, and it is in the nature of things that the interaction doesn't take place. I don't know how you go about intervening in that system, but you must start with that fact of life.

BREEN: Maybe we can return to another idea that was brought up. We should perhaps identify who these policy-makers are. I think this is even more true in the private sector than the public sector. What seems to be emerging is that we don't have policy makers but we have referees. Policies are not made at some upper hierarchical level, but rather a slate of possible policies is put forward, and those potential policies that are put forward in the strongest terms will be adopted. If contradictory policies come from two different sources, then this referee chooses between these policies. That's what can be called decision-making. Then over in the public side, the analysts sit and wait to be told by the policy makers, whether it be a regulator, FPC, or the California PUC what the policy question is. Perhaps we can't do anything but offer the analysis, but maybe we can point out how these tools of analysis can be used and help identify those areas where policy needs to be made. I keep getting the distinct impression (if I go back to my example again of the idea of elasticity being a measurement of responsiveness and then its adoption by local policy makers) that they want this help. They will adopt these tools, but they are not sure how to apply them or to which questions they are applicable. Again there is this huge communication gap between the analyst and the policy maker. Maybe it is not the role of the analyst to fill in this gap, but perhaps an outside group (such as from the social sciences or from some other group that we don't seem to represent very well here) may find a way of filling it. But there is this communication gap.

BENENSON: You're talking about a gap as though it

is a gap between people doing modeling and those making policy decisions. I see a third party coming in, and they are the funders. They are really between policymakers on the one hand and people who are doing the work on the other. To talk about a gap implies that there is at least a potential relationship, and I don't see *that* at this point. At least in my experience, there is need for a contact between people who are doing the work and the funders. The funders aren't the policymakers either. What is happening, is that there are a lot of conflicting policy questions that come up, and there is a sort of the "policy question of the day" that may change from day to day. Yet, the person who has done the funded work or submitted the proposals is expected to answer one question one day and another question another day with the same method. And so the circuits aren't connected at all, or there is a very tenuous triangular connection. One thing that I could think of is that there are people with money who are funding work, and presumably they are getting their ideas from somewhere else—from people who are ostensibly making policy. It would seem that if there was a meeting of three different parties, perhaps that would be a way to get at what's needed. I'm suggesting a direct talk among people who do the work, people who do the funding, and people who are supposedly interested in answering questions and making decisions.

McCALL: Isn't that theoretically the idea of NSF-RANN?

BUDNITZ: What you're saying is that often they fund projects that satisfy the peak load and do not pay much attention to the base load. The peak load changes from month to month, but there isn't the base load to maintain a reservoir of extra capacity to answer the peak loads. That electrical analogy sounds reasonable.

BAUGHMAN: I'm not sure that I agree that there is this enormous chasm between the analyst and the policymakers. It's very difficult to put your finger on any policymakers except maybe for people who announce the project, but it's really a decision making process, a political process. The way our information (the analyst's information) is fed into that decision making process is through the publications and journals. And that does take place.

HOFFMAN: Do the policy makers read them?

VERLEGER: Who reads the journals? They're two to three years late!

BAUGHMAN: I think what that means is that the researchers (the analysts) as part of their responsibility have to try to anticipate problems and bring problems to the front that policy makers don't necessarily recognize.

BREEN: You're just now pointing out essentially the same thing. Okay, you can anticipate the policy question, and you can do your research, but you still have to indicate to the policymakers that this research has been done. You still have to bridge this informational gap. The policymaker needs to go through the research journals or communicate with the analysts. He may talk to them through a third party funding group when he has a particular question he wants to ask. But then usually the analyst has not anticipated that particular question and researched it. So the funding goes on, a project is implemented, and then the answer comes up after the question has been asked with no direct communication and no anticipation of the policy question.

VERLEGER: The peak-period vs. base-load analogy is pretty good here, really. There are two kinds of analysts in this game. The peak-period analyst works generally for consulting firms, and what the policymaker generally does (with the experience we've had) is to call up the consultants he's used in the past, have them do a study which is generally a fairly short study. Washington is full of this kind of self perpetuating thing. The thing that worries me quite frequently is that the long term policy gets formed by the integral of these peak period projects rather than the base load projects. And yet when you turn to academics, (like our Project Independence), the analysts who are interested in the long term project say the time horizon is too short. "I can't get the work done," they say, and they'll beg off doing any part of it. So it's a case where the policy maker is again thrown back. If he tries to get out of his mold and go toward people who have been worried about long term policy, he'll get the door slammed in his face.

BENENSON: Don't forget that the whole idea of energy modeling didn't come out because a few researchers wanted to get together, having nothing else to do, and decide to look at the energy sector. This whole thing is a reaction to a particular set of problems. The problems are national and international in scope. The fact that we're all sitting here now is because suddenly we're being asked by policymakers to answer questions. We didn't anticipate them. Some of them may not even be particularly relevant because not much thought has been given to this area. Using the banking example, which had a little more time to grow, institutions were formed; good research has been done; modeling has been implemented, perhaps to the decision making level. Here, we don't have the luxury of time to wait for institutions to form. We're talking about problems that are national

and international in scope, both long range and short range.

McCALL: In 1970 and 1971, we did a long range energy outlook starting from what we judged to be resource availability and running through a trend extrapolation of demand. One of the very significant things that was obvious and continues to be obvious is that as trends continue, the kind of scenario we used has real supply problems. I am concerned about what this might mean economically. We actually went at the time to a number of people in the field. We went to Sam Schurr at RFF and others; we went to the National Bureau of Economic Research. The answer at the time on this link between energy and the economy was, "Well, first of all, we don't know. That's not something that's been studied." I think it's a reflection of how young this whole thing is. But I think the other answers we got had to be correct, but not very helpful. One was that "It'll all work out because prices will fix everything"—(laughter). That is one kind of an answer. That was the National Bureau of Economic Research answer. And the other answer we got was "It'll all work out because policy will fix everything"—(more laughter). That was Sam Schurr's answer. I do know some decision makers, such as the people in Exxon who eventually carry the responsibility for decisions that are made. I suspect these are not untypical individuals, and I don't cast any aspersion on them when I say that they got to be decision-makers by always have their tails covered. (You just won't get there if that isn't the case.) The energy crisis, the energy problem, the supply shortage was perceived as some degree of uncovering—(laughter). So there is a pull on the part of decision makers for improved tools for anticipating and analyzing energy supply and demand. There is a real pull, but there is nevertheless a serious communication problem. I have one last comment. Something got into an exchange here to the effect that people of this general category accept models that fit their preconceived notions. I don't seriously disagree with that, but I can formulate it in a different way. In order to have any confidence in the models, people have to feel that what the models say about current and recent history makes sense. If they don't feel that, it won't make any difference whether the models are right or wrong. They are just not accepted.

BENENSON: Pat, from what you know of decision makers, is it possible to bring the fabled decision-maker and modelers together?

McCALL: I don't see why not. That's not to minimize the problem. I probably will touch on this again at the close here. One of the things that Ken brought up is that simplicity in the communication of the model structure and its implications is essential, but at the same time it doesn't mean that the fundamentals must be simple. They can be complex. But there needs to be some way to distill the essence of what the model is communicating down to something that doesn't have quite so many knobs on it. The decision maker can appreciate that. The thing that we didn't get into, which I think is also very important, is how the uncertainty aspects are simultaneously communicated along with the behavioral aspects. Decision makers abhor uncertainty, but somehow that's got to be in there. We've made some feeble starts on it. We don't any longer play with the myth that a forecast (one most likely forecast) is sufficient for strategy development.

HOFFMAN: That's a point that concerned me. If you are depending on the model to take the uncertainty out of the decisions, it's a great pressure on all of us.

VERLEGER: By higher prices, you can remove some of the uncertainties. For instance, in the mix of petroleum products, by building more complex refineries, you can cover yourself against the risk that the demand for the product mix may change.

HOFFMAN: This is a decision in response to uncertainty . . .

VERLEGER: Right.

HOFFMAN: Providing more diversity and flexibility I think is an important notion that we've been trying to introduce. We look at a mix of technologies and get around the problem of, say, agriculture, where you have a single crop and single strains and the system is no longer diverse. These diversities can be quantified.

BENENSON: One of the things we want to explore is how these models treat uncertainty. I think in many instances they don't treat it explicitly.

VERLEGER: The question is now "how does the model treat uncertainty?" but "how does the person who built the model treat uncertainty when he is using it?" You make a range of forecasts, and you can narrow the likelihood of being wrong. For instance, we took a risk that the Arabs would not do what they did, and we may have had lower petroleum prices or we may not have, but we paid a very high penalty. We could have covered ourselves against those risks in a systematic planning effort by using storage which would have added something to the petroleum price between 1960 and 1970, but it would have meant that we would not have had the much higher petroleum prices during the last six months.

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KAUFMAN: Without some very clear *a priori* specifications of the criterion function, it is not possible to determine what the expected value of perfect information is. Namely, what is a maximum amount that we should be willing to pay in order to reduce uncertainty in a particular domain? If we simply stick with the kind of descriptive analysis that Marty was talking about, we will never be able to provide any kind of analytical insight into the analysis of those kinds of problems.

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JOINT USA/JAPAN PROJECT ON GLOBAL SYSTEMS ANALYSIS AND SIMULATION (GLOSAS) OF ENERGY, RESOURCES, AND ENVIRONMENTAL (ERE) SYSTEMS

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SUMMARY

Utsumi described a joint United States - Japanese project currently under development for Global Systems Analysis and Simulation (GLOSAS) with special emphasis on the problems of energy, resources and environmental systems. The GLOSAS project is intended to provide decision makers in the participating countries with comprehensive solutions within an international framework. Impacts on domestic economies, international trade and the international monetary system are included. When completed, the project will employ an international computer conferencing network via satellite telecommunications for worldwide interactive simulation modeling.

Global simulation would be carried out by running submodels of socio-economic systems on computers throughout the world linked by the communications system. Typical submodels would be for crude petroleum production, world petroleum trade, and domestic economic and energy models. Such diverse modeling techniques as systems dynamics, input/output, linear programming and econometrics would be employed where appropriate. The models will permit input of policy makers' decisions via interactive terminals. Thus an interactive gaming situation for alternative scenarios will exist whereby the results of policy decisions or strategies formulated in different countries could be exhibited. An objective of the project is to improve cooperation for setting worldwide energy policy.

* * *

I. PROLOGUE

A. Methodology

1. One World

We are now living in a time in which all the peoples of the world have suddenly been brought into close physical contact with each other, by the astonishing modern achievements of the transportation and communication technologies. These technologies regarding our global crises now impinge more immediately, more vividly, and more swiftly on each individual than at any other time in history. Our world on a space-ship earth, with limited natural resources, is now shrinking with accelerated speed.

We live, henceforce, in a world which has been made into one small community, less by political and ideological ideas than by scientific and technological facts. The trends which force us collectively into this community are not the old bonds or agreements between nations, (international or regional) -- rather they are forces which operate across national frontiers and with lessening regard for local territorial sovereignty.

2. Computer Communications (15)

Computer communications can provide commonly shared cultural experiences in a manner unparalleled in human history; that is, the diffusion of a common cultural environment on a worldwide scale. Accompanying this diffusion, there has also been the relatively invisible development of international regulatory agencies, multinational corporations, and new economic blocks and communities whose function and steady growth have been little interrupted by our surface wars and tensions. Many critical decisions affecting the global economy now occur outside of the local national political system. We may well reflect, in terms of real world control, that if all access to such transnationally sustained information networks were cut off, no developed nation could survive for more than a few days.

3. Necessity for Global Interactive Gaming-Simulation

Historically, the computer has been used for collection, retrieval, storing, statistical analysis and mathematical calculations of data. These tasks may

correspond to intellectual labor performed in the back-lobe of our human brain. The computer is now, however, being increasingly used to assist decision-making by individuals, enterprises, and local and national governments. These tasks may correspond to work performed in the frontal-lobe of our human brain. Computer usages for decision-making require systems analysis and mathematical modelling of the assigned problem, which model is to be executed repetitively in order to study cause-and-effects of various decision-makings prior to their applications in practical use. This is the so-called computer simulation which is now forging ahead of computer science and other sciences and technologies.

Up to present, however, computer simulations have been performed in batch mode, recently in time-shared mode, both with a single computer, and simulation models have been developed by a person or a group of persons. With the advent of computer communication networks, simulation models can now be spread to geographically distributed computers in order to assist in the construction of models and data banks by various peoples in an interdisciplinary manner, to utilize computer conferencing techniques for improvement of models and to interact models for gaming decision-making from terminals at various locations, sometimes even in overseas countries.

Thanks to these recent advances of computer hardware and simulation technologies, interactive gaming-simulation has become an effective means of decision-making and personnel training in management, social, economic and political sciences.

On the other hand, computer simulation of socio-economic-political systems has been progressing rapidly in social dynamics and econometrics for business, local, national and international affairs. As the boundaries of their simulation expand making them more realistic, it is increasingly evident that the simulation models require computer communication links for the sake of resource sharing of computer hardware, data banks, simulation software and especially of research resources of interdisciplinary brainware. These requirements are due also to the fact that the socio-economic model building, either with social dynamics or econometrics approach, requires enormous effort even for a single nation, and yet, the model builder knows well the need for interaction with other nations in natural resource allocation, environmental control, foreign trade, and monetary policies.

In the present state of chaos and instability, it is a vital necessity for scientists and simulationists to cooperate not only interdisciplinarily but also internationally in order to plan ahead for the establishment of interactive gaming-- simulation models on a global scale, taking advantage of social dynamics for long-range planning, of econometrics for validation and updating of models, and of political science for decision-making.

B. About Problems

1. The Importance of An International, Interdisciplinary Perspective on World Problems

The energy crisis (as well as problems of pollution, resources depletion, the international monetary system, foreign trade, and national economies) is not the result of a simple, short-term disturbance in the international economic system, but rather is a reflection of a fundamental shortcoming of that system. The underlying principle, heretofore, has been that individual nations had it within their power to control the direction of their economies and to minimize the adverse effects emanating from any outside sources. The wisdom, however, of that perspective has been thrown in doubt by the inability of nations to control inflation and to acquire resources for their economies (at least at the old prices). Given the additional circumstances of limited resources in the world and growing demand due to explosive population increases as well as worldwide higher expectations regarding the quality of life, the interrelated nature of the economies of the world's nations must be recognized as the basic factor in economic planning if the current problems are to be overcome.

The old approach of individual states pursuing their parochial interests in a "zero-sum game" struggle for resources must be replaced by a new approach based upon international cooperation and interdisciplinary coordination. To do less would be to fail to properly recognize the nature of the problem and lead to less than satisfactory results.

2. Technology and Global Policymaking

Combining computer techniques – systems analysis, simulation models, data banks, etc. – with satellite telecommunications and the global computer network provides a capability by which we can test the effectiveness of international policy designs intended to solve world problems. These technologies together (including the computer conferencing system) will create in effect a world-extensive computer simulation model of X-number of countries (utilizing data supplied by the experts, industry, and governments of the participating states) which will be useful in analyzing problems and providing solutions.

Through this integrative use of the latest technology, it will be possible to achieve global policy-making so that all countries can mutually coexist and prosper.

3. Global Policymaking and the Energy Crisis — the World's Foremost Problem

The most critical problem facing the nations of the world is the diminishing availability of energy relative to demand. The oil crisis, resulting from the October 1973 Mideast war, vividly demonstrated the vulnerability of the world's economic system to significant decreases in the supply of energy. In the twenty-year period from 1960 to 1980, it is estimated that the worldwide consumption of per capita energy will have doubled. Today, Japan alone is importing 250 million tons of oil annually, a figure matched by the United States (1970), and it is estimated that a three- or fourfold increase in importing crude oil in the next ten years lies ahead for both countries. Such energy consumption levels by these two countries will exceed the total gross volume of oil produced by the Near and Middle East countries, even without considering the future consumption rates of European and developing nations.

The result will be energy shortfalls, economic stagnation and possibly economic warfare if sound planning and worldwide policy-making are not undertaken. Simply put, the energy crisis will not disappear of its own volition and harsh reality dictates that the best joint efforts of all nations is needed to tackle the problem.

Within the Japanese-United States' parameters of the GLOSAS Project, a joint energy policy is being developed through TOTAL ENERGY simulation models of both countries that will enable Japan and the United States to achieve the most efficient distribution in their respective economies of the gross volume of oil production available from the oil-producing states. A similar world energy policy based on a world TOTAL ENERGY simulation scheme is a logical future step to this joint Japan-United States plan.

4. Global Policy-making, Natural Resources, and Environmental Problems

Realistic global policy-making should also take into account the limits which the factors of natural resource availability and environmental absorptive capacity impose. The problem of meeting growing demand for products cannot continue to be met by the traditional methods of discovering and exploiting new sources of raw materials. Reserves of oil, copper, bauxite, and other essential resources are already under heavy strain due to growing demand (the situation also being confounded by the growing sentiment in producing states to conserve reserves and/or sell at a higher price). In addition, the increase in the destruction of the environment (air, land and water pollution) is becoming a more important factor in calculating the "cost" of increased consumption.

Under these circumstances, a cooperative global policy should be established to foster efficient resource utilization for both consuming and producing countries and to structure industrial organization on a global basis to safeguard the environment.

5. Global Communications, World Trade and the International Monetary Problem

The energy crisis (accelerated by the Mideast war) has also brought into sharp relief the necessity of developing a global approach to the problems of the international monetary system and world trade.

As a result of the large increases in the price of oil, enormous sums of gold, dollars, yen and other hard currencies have flowed into the oil-producing states, giving those states greatly increased influence over the international monetary system and world trade. As prices have climbed higher and inflation has grown, the strengths of the major currencies have dropped, creating a liquidity crisis which could have significant adverse effects on international trade especially as consuming states find it more difficult to pay their bills and producing states bargain to increase their share of "added value". (The "imbalance" in the international monetary system caused by the over-concentration of so-called "oil-dollars" in the oil-producing states not only will adversely affect the more industrialized states, but will not serve the best long-range interests of the oil producing states or the rest of the world's countries as the effect is to "dry-up" international currencies and cutback trade in other vital areas.)

Since trade, monetary reserves and resources influence one another, they should be viewed within a total system. The GLOSAS Project can provide the technological tools by which a simulation system for comprehensive analysis and policy determination on trade and the international monetary problem can be made.

6. Planning and the Impact of Japan's Archipelago Remodelling Plan on the National Economy and Industrial Structure

A prime example of the need for a total concept approach to planning is seen in the case of

Japan. The present Japanese government is strongly advocating remodelling the Japanese archipelago in an effort to correct the adverse effects produced by a growth-oriented, urban-concentrated industrial complex through a dispersal of industry from the cities to the hinterlands of Japan. This plan, however, not only will change the Japanese industrial sector, but will significantly alter transportation, communications, urban life, education, and politics. Moreover, the plan will lead to greater energy consumption, increased resource consumption and deterioration of the environment. Thus the remodelling plan simply should not be viewed as a change in industrial structure, but only as one link in a series of changes throughout all facets of Japanese society. The proper approach to such an undertaking as the proposed archipelago remodelling needs to employ a total-system concept, examining not only industrial structure change in Japan, but also in relation to similar industrial and societal changes in other countries, as required by a global approach for the solution of those problems.

III. PROJECT ON GLOBAL SYSTEMS ANALYSIS AND SIMULATION (PROJECT GLOSAS) (28, 29, 30, 31)

1. Scope

The progress of human civilization is phenomenal in recent decades. The progress has so far been achieved with adequate supply of energy and resources. Since, however, such progress has brought together the exponential growth of population, high consumption of energy and resources, and damage on environment, it is an urgent necessity now to make appropriate decisions on the control and regulation of these subjects in relation to future trends of human civilization, and to the limited supplies of energy and resources.

Currently, the U.S.A. has the highest consumption rates of energy and resources among all countries. The energy used in the U.S.A. has mainly been supplied from petroleum, and the U.S.A., which imports currently 0.25 billion ton/year of crude oil, expects to increase the import two to four folds in the next decade.

Japan, which now has the third largest GNP among all countries, has been highly industrialized in spite of insignificant reserves of energy and resources, but with the main supply of petroleum from the crude oil producing countries. Japan, which now consumes about 0.25 billion ton/year of crude oil, also expects substantial increase in importing petroleum to the amount of 0.6 billion ton/year, when the new proposed modernization plan of Japanese country is accomplished.

On the other hand, the crude oil producing countries, which are now producing about 1.25 billion ton/year of crude oil, cannot and are not willing to increase the production of petroleum.

2. Domain

The domain of this project is therefore focused on the supply and demand of energy and resources in Japan, the U.S.A., the crude oil producing countries, and on the environmental control in relation to the structures of industries and civil-social systems. The primary interests of the subjects are in the order of energy, resources and environment. Further emphasis is also made on the petroleum as the main source of energy.

The regions to be studied by this project will be the four: Japan, the U.S.A., the crude oil producing countries and the rest of the countries.

3. Objectives

The objectives of this project can be listed as follows:

(1) Subjects

(a) To construct adequate simulation models of the supply and demand of energy and resources, and the environmental control in relation to the structure of industries and civil-social systems in Japan, the U.S.A., the crude oil producing countries and the rest of the world.

(b) To utilize the simulation models by experts of Japan and the U.S.A. in interactive gaming modes for the prediction of the future courses of both countries and for the study of the decision-making of the appropriate policies in cooperative manner.

(2) Simulation Technologies

Simulation models of this complexity and size require their construction by experts of the various countries at their own locations. The decision-making players must also be experts in the respective fields in each country.

(a) Distributed Simulation System.
It is therefore necessary to interface the simulation models of each

region with the distributed simulation system by international computer communication networks; that is, the simulation models of each region will be located in the computer(s) in the region, and yet during the execution of simulation models in the total system, the necessary information will be exchanged among models geographically distributed, in computer-to-computer conversational mode via international computer communication networks.

References (24, 25) describe the existing distributed simulation system for air traffic control gaming-simulation. This technique should be acquired and tested within the presently existing computer communication network in the U.S.A., e.g., the ARPA network of the Advanced Research Project Agency. The technique should then be applied to the Project GLOSAS with international computer network via satellite telecommunication.

The first benefit produced by this project in computer simulation technology will be to accomplish and realize the interactive gaming-simulation models with distributed simulation system via satellite telecommunication of international computer communication networks.

(b) Computer Conferencing System. During the development of the gaming-simulation models in each region by their experts, there is a need to collaborate closely among those experts through immediate communication lines. Also, during the study of decision-making on the interactive gaming-simulation, the decision-making players require immediate communication lines for the exchange of their messages.

The international computer communication network, when it is realized, can provide the computer conferencing system, i.e., the messages can be exchanged among the pre-determined number of people on an immediate or on an occasional basis via the computer communication network.

The second benefit produced by this project will therefore be to accomplish and realize the computer conferencing system for the purpose of developing and gaming the interactive simulation models via the international computer communication network.

(3) Computer Communication Network Technologies

In order to achieve the interactive gaming-simulation models with distributed simulation system among the computers geographically located in Japan and the U.S.A., it is necessary to accomplish the linkage of the computers, i.e., the construction of an international computer communication network between the two countries via satellite communication.

The message exchange among pre-determined decision-making players of the interactive gaming-simulation models will also be made by computer conferencing system via satellite telecommunication lines.

IV. RESEARCH DESIGN

The research design of this project is necessarily complex, consisting of four interrelated phases.

1. Phase I

The objective of this phase is to establish an international computer conferencing system for exchange of information among scientists during the development of the system-simulation model. This computer conferencing system will be used further for the study of policy alternatives by decision-makers.

Robert Noel of the University of California at Santa Barbara will convert his present computer conferencing system (16, 17) to operate on the General Electric Corporation's international computer network. This will provide an immediate communication link between project participants in the United States and Japan. Noel's conferencing system was developed for political gaming, hence is not entirely

appropriate for the longer run objectives of this project. However, because the UCSB system can be converted quickly and at a very small cost, and because the team members need an immediate communication link for planning their joint efforts, the UCSB system should be converted first.

Simultaneously, Murry Turoff of the Newark College of Engineering will proceed with installation of the conferencing system that he developed for the Office of Emergency Preparedness (26, 27) onto the G.E. computer network which will provide comprehensive information exchange among participants for the modelling phase of the project in phase II.

In the long run Turoff will be improving his present conferencing system to utilize various application programs and more sophisticated commands for utilization by systems-simulation modelers in the United States and Japan. This will be accomplished in phase III of this project when the more extensive distributive model will be formulated.

A simple schematic diagram of the interconnections of the computer conferencing system through the General Electric international computer network from teams of scientists in the U.S. to Japan via satellite is shown in Figure 1. This figure shows that the PDP-11 computer at Santa Barbara will provide computer conferencing access to Japan through the G.E. network for G.E. terminal users in the U.S., as well as provide access to the Advanced Research Project Agency Network (ARPANET) users.

2. Phase II

The objective of this phase is to demonstrate the computer conferencing system in the development and operation of macro-energy simulation models in the United States and Japan.

The second phase will involve the formulation and completion of a demonstration project, using the computer conferencing system to adapt and operate existing macro-energy simulation models of the United States and Japan. The models will be of the systems-dynamics form (2) with an interface between the Japanese version and the U.S. version developed by Japanese and the U.S. research teams. Data for estimating coefficients in the models will be provided by industry representatives. Modifications to be made to the models include:

(1) provision for running in parallel on one computer,
(2) tuning with new data, as it becomes available, and
(3) interfacing of the two models by an international crude oil flow component (14).

The U.S. energy team will consist of systems analysis and interdisciplinary personnel from the universities, industry, and government. They will be responsible for modifying and extending the U.S. energy model and for providing the interface with the international crude oil flow model to be developed jointly by the American and the Japanese teams. The Japanese energy team will also consist of members from the universities, industry, and government, and will be responsible for the Japanese energy model as well as the development of the interface with the international crude oil flow model.

Initially the combined U.S.-Japanese macro-energy models will be simulated in parallel on the General Electric Nerwork centered in Cleveland, Ohio (here, in this early stage both models will be in the same computer). Also, during this phase, plans will be made and implemented in Japan for making the running of the two models distributively, that is, the Japanese model in computers in Japan and the U.S. model in U.S. computers (24, 25).

The American team will have G.E. terminals at their respective locations through which they can edit the U.S. portion of the combined model, and operate the combined model in a policy testing mode, while they communicate with each other through the computer conferencing system created in phase I. The Japanese team will also edit the Japan portion of the combined model and operate the combined model in a policy testing mode through terminals in Japan. The Japanese team members can also communicate with one another and with members of the U.S. team through the computer conferencing system.

A schematic diagram of the interrelationships for the combined macro-energy model is shown in Figure 2. Here, it is proposed that the G.E. Network may better be interfaced with the ARPANET through the Multics computer (Honeywell 6080) of the Project MAC at the Massachusetts Institute of Technology. This interface may be possible technically without much difficulties, since the computer of the G.E. Network in Cleveland, Ohio, is also the Multics computer.

3. Phase III

The objective of this phase is to develop and operate simulation models cooperatively in the United States and Japan which integrate the components of energy use, resource use, environmental impacts,

national economic system, foreign trade, and international monetary systems.

The third phase involves the development of models in the U.S. and in Japan which integrate energy use (35), resource allocation (3), foreign trade, international monetary systems (10, 34), and environmental impacts. These models will be built by interdisciplinary teams in each country with the interfaces cooperatively worked out by the two teams using the computer conferencing system established under phase I. Research under phases II and III will be carried out with industrial and governmental participants to insure use of reliable data and testing of relevant policy alternatives in both the United States and Japan.

(1) Both countries will organize working teams of specialists for each component.
(2) Each working team will conduct systems analysis, build models and data banks.
(3) When each sector model has been built, the teams of each country will integrate them into one national model.
(4) When both countries have build the jointly coordinated models, those models will be stored in computers and interfaced by satellite and the computer network, thus enabling the operation of a simultaneous distributed simulation system.

The distributive E-R-E (energy-resources-environment) simulation models and the interfacing of an international foreign trade model is shown in Figure 3. The computer conferencing and the distributive simulation models of the integrated type, that is, models housed in computers in their respective countries, would be linked by satellite between the United States and Japan as illustrated in Figure 3.

The structure and components of the integrated systems models on the United States side and the Japanese side are shown in Figure 4. The communication linkages are also shown in Figure 4. These include (1) display units for showing simulation results to scientists in each field of expertise and to decision-making players and (2) display units for information exchange among scientists and decision-making players. The operation of distributive models and the information exchanges will be accomplished via satellite.

4. Phase IV

The objective of this phase is to promote the utilization of the international computer conferencing capability to exchange scientific information by scientists throughout the world.

This phase of the project is oriented towards promoting the wider usage of computer conferencing systems and distributive computer simulation technology. With the establishment of the conferencing system by Noel and Turoff, it will be possible to provide a means of information exchange among scientists of various international projects.

For example, L. Klein at the University of Pennsylvania could use computer conferencing and distributive computer programming for his Project LINK (10, 34) to speed up communication among international participants. In addition, such projects as the International Biological Program (IBP) (9, 36) could be assisted by computer conferencing at such locations as Oregon State University, the University of Washington, and Colorado State University at Fort Collins. Political gaming simulation at the University of California at Santa Barbara would also be expedited by the computer conferencing system envisioned by this project.

The fourth phase will also establish a management center for the organization and operation of the international computer conferencing system in order to promote the utilization of this technology by scientists and decision-makers throughout the world. This center will coordinate the use of the international computer conferencing system by existing or developing international projects in such areas as engineering, economics, biology, medicine and systems science.

The development of computer conferencing technology can be utilized in the future, by any large organization on an international or national scale, public or private. For example, the United Nations, universities, libraries, and associations could use a computer conferencing system for transacting much of their information exchange efforts.

V. RELATED PROJECTS AND SIMULATION MODELS

Figure 4 shows the outlines of hierarchical structure of the gaming-simulation system for the energy, resources and environment. Every submodel will need to be constructed with the system dynamics approach.

1. World

A. Related Programs

(1) World Dynamics Model

The world dynamics model here is a kind of an executive main program, and will provide

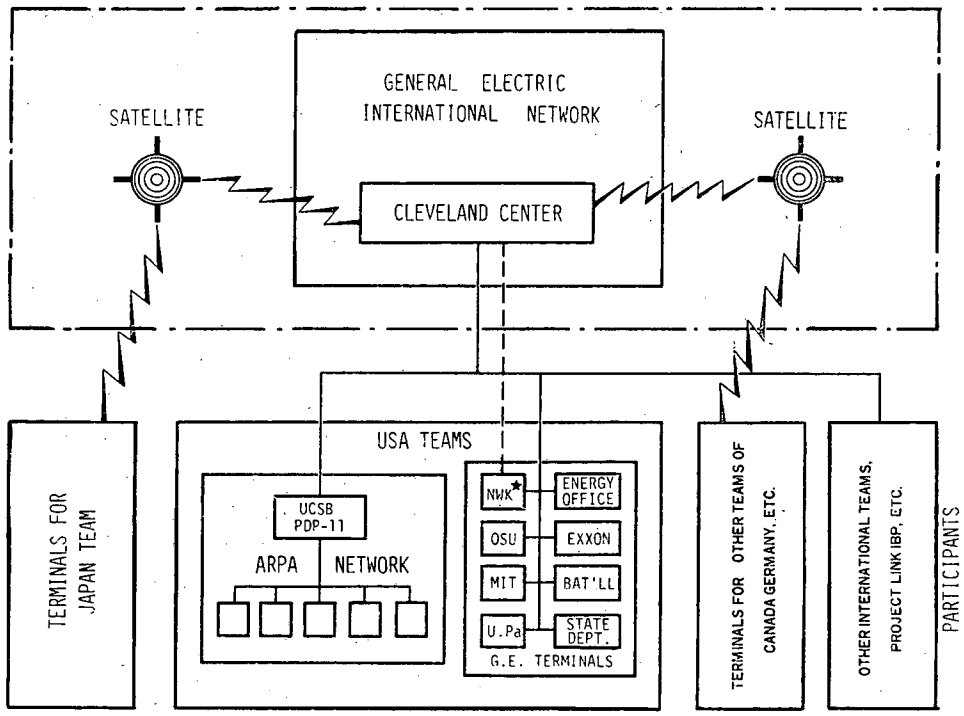

Fig. 1. Computer conferencing system. *Initially conferencing will be exclusively via the existing systems of UCSB, after interfacing UCSB's PDP-11 with the GE network. In the third phase, the conferencing software of Turoff will be available among the participants, from the Newark PDP-11, for direct conferencing through the GE network.

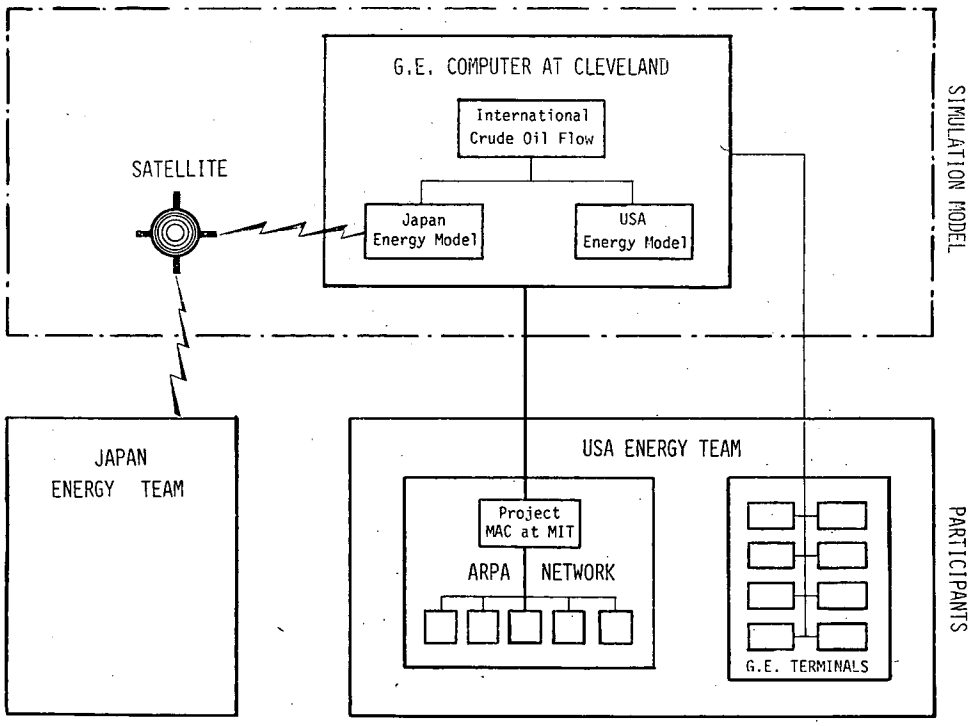

Fig. 2. Phase II: Simulation with combined Macro Energy Model.

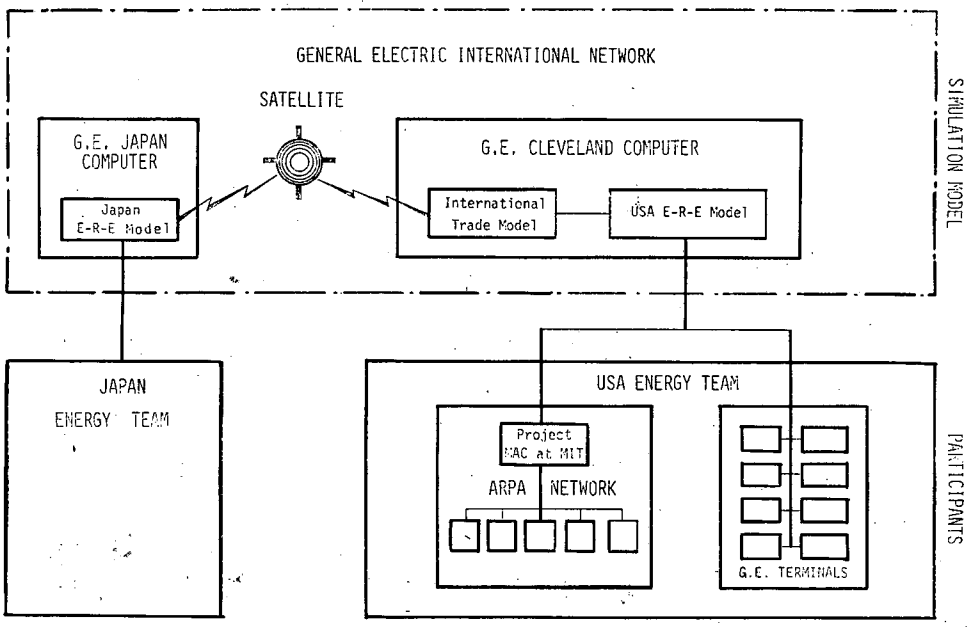

Fig. 3. Phase III: Distributed simulation with integrated Energy-Resource-Environment Model.

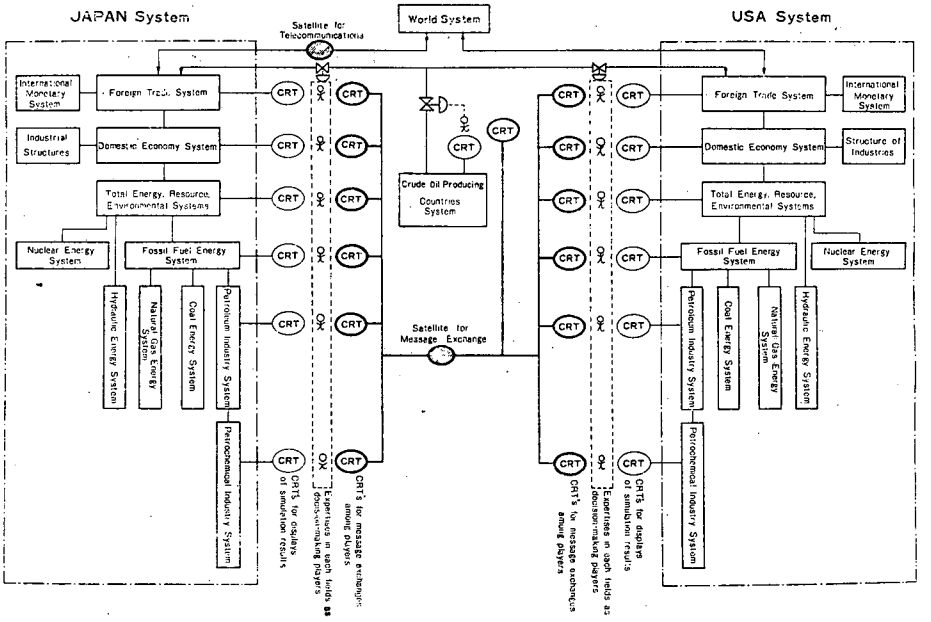

Fig. 4. Structure of integrated models and communication network.

a common area through which the information of variables will be exchanged among the models of each country.

(2) "Dynamic Behavior Crude Oil Production in Middle Eastern Oil Exporting Countries" (14)

This is a systems dynamics model of policy simulation with which decision-makers in government level could simulate the behavior of crude oil production of Middle Eastern Oil exporting countries, such as Iran, Saudi Arabia and Kuwait, and identify effects of alternative policies in relation to their domestic economies. From this model, crude oil will be imported to the USA and Japan models, when all three models are interfaced together.

(3) "World Oil Trading Simulator" (18)

This is a linear program for oil transportation and refining on a world-wide scale. The world is sectorized into twelve regions. Considered in this model are the following: Amounts of crude export from oil producing countries, yields depending on the types of crude oil, sulfur content, types of refineries, desulfurization, cracking capacities, regulation for sulfur content, price of crude, refining operation cost, demand of each product in each region, transportation cost, tariff, etc.

2. Japan

A. Related Programs

(1) Total Energy Model

Japan total energy models have been constructed in systems dynamics approach by the Agency for Science and Technology of Japanese Government (1). The models are now being refined and expanded. In each model below the total energy model in Figure 4, the resources and environmental systems will be included.

(2) "Japan Interfuel Competitive Total Energy Systems Dynamics Model" (32)

This is a revised version of a similar model of the USA developed by M. L. Baughman of MIT (2) and has been installed in the General Electric/International Computer Network System by the Japanese team.

The Japan model will have a unique feature compared with the Baughman's original model, i.e., inclusion of structural expressions for the price matrix. In the future, the Japan model will be rewritten with IBM's Continuous Systems Modeling Programming (CSMP) Language, in order to add a linear programming submodel for the representation of the Japanese government's decision structure on the selection of crude oil types imported from oil producing countries. The Japan model will also include explicit expressions for pollution, social opposition against pollution, shortages of industrial sites, and a linear programming submodel for the selection of fuel oils with appropriate sulfur content and price structure.

(3) Electric Energy Model

A total Japanese electric energy model has been developed in systems dynamics approach by a central research institute of Japanese electric power companies (1).

(4) Gas Energy Model

The gas energy model may soon be developed in systems dynamics approach by a municipal town gas company in Tokyo in the near future.

(5) "Japan Petrochemical Industry Systems Dynamics Model" (33)

This is an aggregated model which represents Japanese petrochemical industries and will be a subset of the Japan Petroleum Refining Industry Systems Dynamics Sector in the interfuel competitive model mentioned above.

(6) Other Programs

Other related programs which will be integrated with the above models in Phase III of this proposal include the following:

a. "Japan Archipelago Systems Dynamics Model" (11)

This is a regionally disaggregated model with 13 regional sectors of Japan. Each region consists of primary, secondary and tertiary industries. There are flows of capital, resources, labor, etc., among industries and also among sectors.

This model has been nearly completed by the Japanese team and can serve as the "reference model" for Japan with augmentation by yearly accounting formats such as I/O (Input/Output).

b. "Japan Macro National Economy Systems Dynamics Models"

These are aggregated models representing the Japanese national economy.

i. Revised Version of Canadian Dynamic Model

This is a revised version of the "Life Cycle of Canadian Economy Model" built by N. B. Forrester (5), modified to Japanese conditions. This model has nearly been completed by the Japanese team.

ii. "T. J. Gordon's Model" (6)

This is a probabilistic systems dynamics model with a submodel based upon a scenario of probabilistic events and also cross-impacts of the events upon the Japanese societal economy. This model has been completed by T. J. Gordon of the Future Group under contract from the US government.

iii. "H. Hori's Model" (7), (8)

This is a systems dynamics model with some 1,000 structural equations expressing mainly the behaviors of the Japanese macroeconomy. It may serve to provide both short-term (one to two years) and long-term (twenty to thirty years) economic forecasting.

c. "Japan Industrial Energy Input/Output Model"

This is an input/output model representing the usage of energy by individual industries in Japan. This model is now under development by Mitsubishi Research Institute and has a US counterpart developed by W. A. Reardon of Batelle - Northwest (19).

d. Japan National Economy Econometric Models --

In order to cover the sectors in the Japanese national economy which are ambiguous and difficult to express structurally, the Japanese national economy econometric models will be incorporated with the foregoing. The following models are presently being developed or are already existing:

i. "Japan National Economy Econometric Model with Pollution and Environmental Sectors"

This is a heterogeneous model combining pollution and environmental sectors built by a systems dynamics approach and a Japanese national economy model built with an econometric approach. This model is now under development by Japan Energy Economic Research Institute.

ii. "Japan National Economy Econometric Model"

This is an ordinary econometric model on foreign trade. This model has been developed by Mitsubishi Research Institute with a large data bank. (22), (23).

e. Japanese Foreign Trade Model

A Japanese foreign trade model has been developed by Mitsubishi Research Institute (MRI) with an econometric approach (23). It may be necessary to convert this model into a systems dynamics model.

B. Japanese Data Sources

Besides the data bank of the Japanese national economy at the Mitsubishi Research Institute, similar data sources are available from : the Japanese Energy Economic Research Institute, and the Japan Economic Research Institute, and the Economic Planning Agency of Japanese government. Industrial data for petroleum and petrochemical industries are available from the Ministry for International Trade and Industries. Also, industrial data are available from various trade and manufacturing companies.

3. United States

A. Related Programs

It would be necessary to develop the hierarchial structure of simulation programs in mirror image to the Japanese sector.

A state-of-arts' review report on systems analysis and computer simulations technologies available in the United States to cope with the energy crisis was compiled by the Decision Sciences Corporation as a project of the Office of Environmental Quality in the U.S. Government (12, 13). The report shows that approximately 100 studies have been conducted on various aspects related to the energy crisis (fuels competitiveness, environmental impacts, technological assessments, etc.)

Also, it should be noted that the collection of papers presented at a "Seminar on Energy Modeling" held in Washington D.C., (20) compiles various energy simulation works with the uses of input-output, linear programming, econometrics, and so on.

(1) "U.S. Interfuel Competitive Total Energy Systems Dynamics Model" (2)

The energy model of U.S. fuel consumption built by Martin L. Baughman of MIT is the only one cited in the Decision Science Corporation Report which uses the systems dynamics approach, and was used extensively by the U.S. Office of Environmental Quality. This model will serve as the basic U.S. energy model in the GLOSAS demonstration project in Phase II.

(2) Electric Energy, Gas, Petroleum, Petrochemical Industries Systems Dynamics Models

These models may have to be developed in the U.S. The hydraulic, coal and nuclear energy models for the U.S. with systems dynamics approach will also have to be developed.

There are numerous other related simulation models for various energy sources, regions and methods. These models and their authors will be called for their cooperation with this GLOSAS Project as the project proceeds.

(3) Domestic Economy Model

L. Klein of the University of Pennsylvania may be able to provide a U.S. domestic economy model constructed by econometric approach. This is the so-called Wharton model of the U.S. economy (4). The Systems Dynamics Group at Massachusetts Institute of Technology may also be able to provide a U.S. domestic economy model constructed by systems dynamics approach.

(4) Foreign Trade Model

Project LINK developed under Klein's direction at the University of Pennsylvania (10, 34) may also be able to provide a U.S. foreign trade model constructed by econometric approach.

4. Additional USA-Japan Interaction

(1) DYNAMO Language

This language is mostly used for systems dynamics modeling, such as the above mentioned Baughman's model and Forrester's model. The creator of this language, A. L. Pugh of MIT, is now installing it into the G. E. system. He is cooperating with the Japanese team so that the Phase II demonstration project can be accomplished within the project time schedule.

(2) POLIS Computer Conferencing System

R. C. Noel of the University of California, at Santa Barbara, coordinately with the Japan team, is installing his computer conferencing system into the G. E. International Computer Network System. This conferencing system is now in the testing phase internationally among interested people in the U.S., Japan and Canada and is the key for the initial coordination of project participants.

5. Interactive Decision-Making Mechanisms

After modifying the respective Japanese and U.S. energy models to achieve interfacing, the GLOSAS Project proposes to conduct multinational gaming among the energy models in computer-to-computer conversational mode via the global computer communications network and communication satellite.

Referring to Figure 4, the flow of petroleum from the crude oil producing countries will be regulated by their own decisions as well as by the decisions made by the decision-making players of Japan and the U.S. The information on petroleum flow will be cascaded down from the foreign trade model to the petroleum industry model, which will be supplemented with the petrochemical industry model.

The decision-making players in Japan and the U.S. will be equipped with the computer conferencing system. The conferencing system may be provided through a different computer other than the one pro-

cessing the simulation model. Each decision-making player in Japan and the U.S. may need two terminals, one for the display of the results of the simulation model, and the other for the display of the messages transmitted with the conferencing system.

VI. IMMEDIATE APPLICATIONS OF THE GLOSAS PROJECT FOR SOLUTIONS OF ENERGY CRISIS IN JAPAN

1. Competition for Crude Oil between Japan and the United States

Demand for oil in Japan and the United States (as well as the rest of the world) will grow in the foreseeable future. Because the oil-producing states, however, are generally against increasing oil production, the prospects for a race between the United States and Japan for the available crude oil supply appears imminent if past patterns are adhered to.

The GLOSAS Project solution: Conduct joint systems analysis, computer simulation and consultations among experts on the energy problem through satellite telecommunications and the computer conferencing system so that supply structure, demand consumption rates (depending on oil prices) can be determined on a long-range basis as part of a mutual policy for Japan, the United States as well as the rest of the world.

2. Impossibility of Developing Additional Refinery Capacity within Japan

Additional refinery capacity is needed if Japan is to be able to meet the expected increased demand for energy (the greater part coming from fossil fuels, particularly oil) which will accompany the changes in Japanese society. However, because of previous pollution, people's opposition movements, shortage of industrial sites, etc., it is not possible to build that need additional capacity in Japan.

The GLOSAS Project solution: To meet the growing demand for energy, Japan will have to locate additional refinery capacity in foreign countries. GLOSAS Project analysis can determine when those refineries should be built and what capacities they should have. In addition, it will help optimize foreign and domestic investment in the oil industry and establish a macro-management plan to achieve efficient distribution of energy among energy-dependent industries. Moreover, this will allow Japan to re-focus its foreign policy to achieve the necessary collaboration with other governments to build these refineries and industrial complexes and to give Japan sufficient time to make financial preparations.

3. Growth Pattern of the Japanese Petrochemical Industry (33)

The third problem which the GLOSAS Project will focus upon is related to the growth pattern of the Japanese petrochemical industry in relation to the expansion of its plant capacity. Having been a central part of Japan's spectacular growth in the postwar era, the petrochemical industry now faces problems of pollution, people's opposition and the lack of plant site availability.

Proposed GLOSAS Project Solution: the GLOSAS Project will conduct a study to forecast the future of this industry. As demand will exceed domestic production, Japan will have to rely upon imports to make up the difference, a situation which will involve the investment of enormous sums in foreign countries in the next five to ten year period. The study will enable policy-makers to determine appropriate investment levels, both domestically and internationally, in the industry.

4. Japanese Domestic Fuels' Competition, Distribution and Environmental Problems (32)

Development of different sources of energy (oil, coal, natural gas, nuclear) means that a method for determining optimal distribution of energy sources among selected industries is needed.

Proposed GLOSAS Project Solution: Project studies can determine the appropriate distribution among competing fuels to achieve the most efficient allocation according to the demands of industry. It can also help locate appropriate investment in new energy research, determine which industries should be shifted to foreign sites, determine the possible growth in a specific industry (including level and rate), project energy consumption for each industry, and recommend steps for minimizing environmental problems.

VII. OTHER BENEFICIAL EFFECTS OF THE PROJECT

The following is a list of some of the important secondary effects which will derive from this project.

1. Promotion of Mutual Understanding and Expertise

As the task of solving various problems in Japan and the world will be jointly undertaken by experts from the participating states, the project will not only advance technology, but will also lead to mutual understanding, raise expertise and enhance the global perspective.

2. Security for Sensitive Information by using a Distributed Computer Network

Since the project interfaces the models of each country simultaneously through satellite telecommunications, each country's models and data banks will remain stored in computers within the respective countries, and therefore the transfer of sensitive data across national boundaries is no longer necessary, thus assuring national security.

3. Improvements in Systems Dynamics and Model Building Technology

Since a large number of experts will be responsible for the computer simulation, model building, and systems analysis of each sector, the performance capability of each model will be increased and the efficient utilization of techniques and resources (hardware and software) will be promoted.

4. Develop Japanese Computer Capability

Also as a result of this project, Japan's computer capability will be enhanced. (One of the reasons for a lag in Japan's computer capability is the lack of computer applications for management and policy-making in business and government). Significant advances in the following areas of the Japanese computer industry will be made:

(1) computer simulation techniques needed in management and government,
(2) development of softwares in support of computer simulation,
(3) development of computer hardware needed for computer simulation,
(4) a computer network in Japan,
(5) dissemination of computer conferencing technology,
(6) promotion of global satellite telecommunication technology.

The formation of a domestic integrated computer network in Japan faces the problem of combining the different kinds of computers which Japan possesses. Japanese experts, however, are confident that this problem can be overcome since a similar difficulty was surmounted in the United States.

It is anticipated that the successful combination of the medium-size Japanese computers will give Japan a computer capability equivalent to American large-scale computer capability.

5. Internationality of Models

This project will also result in the construction of models of increased reliability. As the concern of this project are those problems which need to be solved by a worldwide perspective, this project will conduct systems analysis and model building on a global scope, but will have experts of the various countries conduct the data gathering and model building of their own countries. Tentatively planned for the latter part of the second phase of this project is the building of an international management center to handle coordination of this project and to assist in integrating models from Canada, Germany, Venezuela, Norway, etc., as those countries complete construction of those models.

6. Cost Savings on International Project through Joint Coordination

Finally, since the project is international in scope, substantial savings result from reduced development costs can be obtained by avoiding the duplication of projects through the joint development of the technologies to be used in the GLOSAS Project. Such international joint development is also realistic, given the fact that the interests of a particular country are quite susceptible to being influenced by the politics and economics of other states and thus will lead to greater international cooperation.

VIII. CONCLUSION:

1. Electronic United Nations to be established by Experts of a Global Invisible Research Institute

In addition to the unique utilization of national energy models in computer-to-computer conversational mode, the GLOSAS Project will utilize the computer conferencing system which will enable the participating experts to exchange messages and collaborate closely and immediately during interactive gaming-simulation. Thus, on the one hand, there will be gaming between models via satellite telecommunications, and at the same time, there can be in effect face-to-face consultation among the experts via the same satellite telecommunication.

By using the computer conferencing system, we will create a "global invisible research institute", gathering together experts from all parts of the world whenever they desire and/or are available for the integrated use of their "brainware" for the betterment of mankind. The aforementioned approach of interfacing the computer models of all countries via satellite telecommunications by the experts of the global research institute may correspond to establishing an "electronic United Nations".

In summary, the information network of the GLOSAS Project will be created by various experts in every country with their distributed responsibilities. Hence, its spirit is a truly democratic one which has been longed for not only by computer simulationists (21) but also by peoples of the world.

2. Epilogue

The social problems facing us now necessitate the extension of their boundaries to include the close interactions of foreign trade, natural resources allocations, and even political internation relationships.

Computer simulation of various subjects in worldwide scale is an unavoidable necessity now and in the future. Such large scale computer simulation cannot become practical unless it utilizes multiple computers, instead of a single one, linked with a computer communication network, and unless multiple working teams scattered around the wrold will exchange their know-how and data resources through the computer network.

Global collaboration of social and technical problems is now economically, technically, and practically possible, important and timely. Different parties should construct and study simulation models of their regions. Such models should be tied together by means of communication satellites to study their interactions and influences on a truly global scale. What is important now is to establish suitable ground rules, reasonable assumptions and a common set of premises for the various modelers to to work from.

Such team-work may promote the peaceful collaboration among nations. Today is the day of cooperation of people of various disciplines and of various countries. The collaboration of computer simulationists with global computer communication network will also bring about a bright future.

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SUMMARY OF DISCUSSION

The problem of validating a model composed of a variety of submodels was explored. Two difficulties often arise from combining models: 1) the structure implied by the combination may bear no relationship to the phenomena being modeled; 2) while the submodels may be predictively accurate, the combination may not be. It was suggested that a highly aggregated representation of the total system be used as a cross-check.

Past experience has shown that model builders from each country have a biased view of their country's role in the world picture. This results in serious inconsistencies when models from these countries are combined. Perhaps a unified effort is more valuable than an attempt to coordinate the independent efforts of various countries.

Thus far traditional methods have been used to combine the submodels in the system. However, the complexity of the problem of combining models may be such that new methods may be required in order to make the combination successful. It was pointed out that systems dynamics is not the only method available for incorporating dynamic interaction between variables. The work of Hoffman, Hudson and Jorgenson, and Griffin is directed toward this sort of interplay without using systems dynamics. However, their work does not always state clearly the causal relationship of various components in the social structure as systems dynamics attempts to do.

Because systems dynamics can incorporate many methodologies, each of which has its own weaknesses, the question arises concerning the type of policy question that could be answered using this approach. The model can be used to discern the social and economic structures causing gaps between supply and demand and to set realistic production targets for closing these gaps. To obtain a more explicit consideration of the action options for policy makers, a more micro type of modeling is necessary. It was not clear from the discussion how the weaknesses of each of the components would impinge on the accuracy of the results. Perhaps this cannot be determined until the models are actually combined and tested. This led to the question of whether systems dynamics brings anything new to modeling or whether it is simply a means for combining existing models. The question of implicit assumptions within the structure of the model was discussed and contrasted to the assumptions made in linear programming. In the latter technique if the supply and demand constraints are exogenous, then most of the assumptions are explicit. This is not true in the case of systems dynamics, where there are implicit assumptions represented in the coefficients. Consequently, documentation of these implicit assumptions is needed to provide a complete explanation of the model.

The advantages of combining models cannot be determined a priori. Long term research in model development must be done to demonstrate where the advantages lie. But there is an immediate need of criteria to apply for funding research in model development, especially in combining models. Two criteria were suggested: 1) the combination appears promising from an intuitive and intellectual point of view; 2) the model will enable the policy maker to ask new policy questions. Even a loose type of coupling between models would be advantageous as it would provide a consistency check between them. For example, an econometric model which provides information about price responses could be combined with a Brookhaven type model which provides technological detail. There are also potential advantages to combining a descriptive model such as systems dynamics with a prescriptive model such as linear programming. The incorporation of behavioral research is attractive but the method for making such a combination is not clear. For example, the systems dynamics model which is described by Utsumi calls for a description of the behavior of political and social groups. Here there is clearly a need for behavioral research. A method suggested was to correlate the complaints registered by social groups with the pattern of capital investment. Social behavioral patterns can be directly incorporated by having decision makers from each country participate in the interactive gaming simulation. One of the underlying problems of combining models is that they are often based on different disciplines. A speculation was made that the combination may result in a mutual education process and a redirection of the disciplines that are combined.

DISCUSSION

KAUFMAN: What I would like to do, rather than try to discuss individual pieces of this, is to mention some general methodological issues that arise in doing research of this kind. I'm sure we're all familiar with them in one form or another, but they would appear to apply with particular force here because of the size and scope of the modeling effort. The first issue concerns the implications of synergism between submodeling in various countries and sectors. Often you can build an empirically validated submodel for a variety of sectors and put them together and be terribly surprised, both because of the structural implications of what the aggregated model yields, and because it lacks any kind of predictive viability even though the sub-components seem to be both predictively and structurally accurate. The question is to what degree have you attempted to validate this in a somewhat different way by perhaps structuring a highly aggregated representation of the total system (just as macro-economists do) as a cross check to keep hold of what's going on in this tremendously complicated interface?

UTSUMI: Well, it all depends on how we proceed and how much technology we foresee. We have to test our approach with a very small program.

VERLEGER: Let me interject here. I don't like to get commercial but Data Resources (the company I work for) has in fact done something like this in macro-forecasting. What we run is a series of macro-econometric models of the U.S., Europe, and Japan. We try to pull economists together. It turns out to be a tremendously difficult problem. The thing that is interesting in the trade flow and the thing that is really giving us a bind now is this: we attended a conference in Europe last May for corporations interested in forecasts in Europe, and we had an economist from each of the different countries get up and talk about the effect of higher oil prices in their balance of trade. Their accounts can be summarized as follows: First, higher oil prices are going to mean a tremendous trade problem. Second, "It does not effect my country." So when you add the whole thing up, it's just totally inconsistent. Then you go to link these econometric models or systems-type models, and, just as Gordon suggested, the linkages suggest that the whole system does not hold together. Really the conferencing system becomes somewhat less than optimal. It really boils down to going back to the old, more traditional ways of economic analysis almost without computer to figure out where the dislocations and the structural changes are going to occur, especially with respect to Japanese growth. Then you come back and build up again.

KAUFMAN: Well, they're not incompatible efforts at all. They're really coming from two different directions. But they're hard problems.

VERLEGER: They're incredible problems.

UTSUMI: Here in the U.S. you people may not find it necessary to consider other countries. But in Japan we are quite sensitive to other countries' behavior.

KAUFMAN: I think Phil is saying just the opposite. I think he was saying that, even from the U.S. point of view, when you begin to consider the kind of major dislocations (in money flows, raw materials availability, and so on) that as big as the United States is, it still must consider precisely those kinds of things. That makes for a certain kind of unity of effort when we are faced with the same problems. This sounds to me almost like a quantum jump in the scope and complexity of modeling. It raises another methodological issue and that is this: in looking at the submodels of what people are doing, we find they are using currently known modeling technologies. They use the techniques of inference for validation of the submodels and put these things together with a currently known methodology for aggregating them. That includes computer methodology as well as modeling methodology. But one can ask, when you get into problems of this scope, do the problems themselves suggest certain new kinds of methodological problems that demand additions to our kit of analytical tools that we haven't considered? You see, most all of the econometric work here is pretty much based on the known technologies. You generally know their properties. The art becomes one of taking these tools and cutting out models that work and which you validate. Perhaps there are some things lurking here that demand a totally new concept in models. I have no answer to that; it's just something that comes to mind.

KAUFMAN: I have just one marginal comment on a small piece of this. You're talking about cross-impact methods and matrices. In a way this is a methodology for eliciting subjective or personal probabilities about complex bundles of events in which you have probabilistic interactions among them. In looking at some of the original stuff, there were some serious mathematical deficiencies in the structure of cross-impact methods, at least as they were presented in the literature a few years ago. That is saying it charitably. To say it uncharitably,

the mathematics is wrong. I'm curious as to whether cross-impact methodologies have been re-directed so that there are no logical inconsistencies?

UTSUMI: Yes, they have been by now.

KAUFMAN: Okay. That's fine. I was directing attention to some logical deficiencies that were present in the method as it was originally published. It's like looking at a subjective problem in which you consider first order interactions and ignore the higher order interactions. That in itself is an interesting topic for research because in many of these problems, it's probably not sufficient to consider the conditional probability of A given B (but unconditional as regards CDEFG and so on) when you're dealing with critical events. That kind of limitation is counter to the methodology that you have suggested because, in looking at this petro-chemical example, you have everything interacting simultaneously so all contingent events can impact on all other contingent events.

UTSUMI: But the other point is that in this kind of simulation all the parameters are set at time zero. They do not change during the execution of the model. But in the real world, if something changes, people will react. For most econometric techniques, everything is set. But this has to be changed.

VERLEGER: I'm afraid I have to disagree with you in terms of the discussion of econometrics where the parameters are preset. I think that the work Hoffman talks about, although it is not econometrics, and the work of Hudson and Jorgenson has been very much in the spirit of what you're talking about. You're looking at the changing parameters. Also there is the work Jim Griffin and Jerry Stams have done in the past; that is, looking at deriving cost curves for petroleum refineries, and they are almost getting at this Markov process that Gordon's talking about. From looking at the process analysis and looking at the additions by activity, it becomes almost a Bayesian decision analysis.

KAUFMAN: There's a certain richness in the nature of the models that are being suggested here that just were not present in the past in which (to use a bad word) the elasticities essentially are functionals.

UTSUMI: . . . and also such components of deciding the prices are all determined by experts, component by component, so we are quite sure of the changes in price with the systems dynamics approach.

BENENSON: One of the things we're trying to get at is the relationship of the models to the policy questions. As we've been talking yesterday and today, it seems that we can see some types of policy questions for which a method is suitable, perhaps, and then others where it's obviously unsuitable. Here, we have a combination of methods. What I'm wondering about is what happens when you want to answer policy questions? What can you do when you have different types of weaknesses at different points in this whole system?

UTSUMI: Systems dynamics gives you the behavior of the variables in the real world. You could treat the results of the program as if it is the real world. Data banks and its use with econometrics can verify the systems dynamics results. Next, consider linear programming. In Japan decision making takes place every year. At the end of the year, the linear programming results will provide a production target in the following year, so in simulation, we can use the optimum target from linear programming and feed it back to the systems dynamics model. Each methodology has its advantages but one methodology can not override another. Then, the human interactions during the execution of the models can provide "simulated" decision-making behavior. However, since the modeling of human behavior is the most difficult one, we should not waste our time and effort programming them, but rather, we should simply let real men participate in the interactive gaming simulation.

VERLEGER: There's a general question I'd like to ask both you and Ken Hoffman. We were discussing yesterday the question of simulation with the Brookhaven model. You set the shadow price of oil in one of your simulation steps at 42 dollars a barrel. Do you realize that your supply elasticities need to be changed?

HOFFMAN: Yes, there needs to be a supply elasticity other than zero.

VERLEGER: I wonder sometimes, when you're dealing with these very big systems, whether you really can get a handle on all of the problems at one time. We are facing the same problem with macro-econometric models or input-output models of the economy. They sometimes get too large to ever produce a consistent solution, unless perhaps Larry Kline will be able to do it with a macro model. He has a very strong feeling as to what the key components will be. I guess the question I'm trying to ask is "do you think you capture everything by repeatedly running a simulation of a pretty large model and adjusting for things like that?"

HOFFMAN: Well, I don't consider our model a very large model. I have a feeling for what the basic problems

are. There is inter-fuel substitution, particularly between the electrical sector and the non-electrical sector. In getting these high shodow prices, when we were forcing substitution to the extreme, forcing the substitution of electricity for oil, you get into some areas where it is very difficult, because severe reallocations of energy flow in the system have to take place. At some recent meetings we followed Deams of the U.K. in the presentation of his model. He comes up with 16,000 variables and 4000 constraints. Even our huge expanded model is only about 600 variables and 100 constraints.

UTSUMI: The model can really be very small. Don't be scared of large aggregations.

HOFFMAN: There's the question, too, of implicit assumptions within the structure. In the LP structure, regardless of how large it is, if the demand constraints are exogenous and if the supply constraints are exogenous, there really isn't that much built-in in the way of hidden assumptions. I don't think that is the case with systems dynamics. There is a tremendous number of implicit assumptions represented in the coefficients, and I would recommend Nordhouse's critique of systems dynamics.

UTSUMI: If one of the variables in systems dynamics is insensitive to the rest of the variables, we strike that variable out.

HOFFMAN: Well, how do you get at that sensitivity?

UTSUMI: Just test them one by one with experts' suggestions. That is the essential feature of computer simulation.

BENENSON: I still don't understand what types of questions one can answer from this type of model. I wonder if you would give some examples of questions that you would pose which this model could then respond to.

UTSUMI: As I described here on the gorwth of Japanese petrochemical industry, there is a severe supply and demand gap of ethylene after 1980. In order to meet this gap, decision makers in Japan have to be aware of the situation, and I think that would be the type of problem to which this analysis could be applied.

KAUFMAN: That's really an issue that goes back to the essence of what you mean by a descriptive model. It could be many things. One possible utilization of a descriptive model of this kind is simply to set the stage for the economic and physical environment as it may be in the future for example to recognize that there's going to be a tremendous demand-supply gap. That is a very important input if you're at a point where you don't recognize that it's there. Conditional upon recognizing that it's there, you may want to peel a few more layers off the onion and say that conditional upon that obtaining, let's now redirect the model towards a more explicit consideration of the action options that policy makers have in that period of time when faced with those facts.

VERLEGER: Wouldn't that call for smaller models?

KAUFMAN: A different kind of modeling, more micro-modeling. You go up and down the scale. I guess the principle is that the utilization of the model has to be put into relation with the policymakers' state of information at a given point in time. So the idea is not that you build one model, but that you're talking about a dynamic process, a sequential process in which there is a sequence of models built.

UTSUMI: Somebody may suggest that the social structure is going to change, so we have to incorporate this factor to test and see whether it's right.

SPARROW: This is the famous Forrester ploy. This is what gives me some concern. The Forrester ploy is that you make a systems dynamics model; then if someone comes along with a model that isn't in it—then suddenly, amoeba like, the systems dynamics model expands to include it. Now what I am wondering is what does systems dynamics bring besides this capacity to envelop?

UTSUMI: One contribution that it makes is that it sheds light on the structure of social mechanisms.

ETON: Many people have been talking about marrying different models with different models. Many of these are in the future tense, combining this and that and the other thing, and it's really unclear exactly what are the benefits of the marrying of the models. Is it something in which you get anything other than garbage-in-garbage-out? What are the conditions for the successful joining of models that have an entirely different presupposition?

KAUFMAN: Well, isn't the motivation behind the marriage the fact that on the one hand if you're predisposed to do econometric modeling, really want to estimate something? It's very hard to build a model that is essentially representative of, say, a system of 5th-order partial differential equations with stochastic components in it and do any econometric estimation. That's relatively beyond the capacity of our econometricians at the moment. But on the other hand, with the simpler representations, you can do estimations. So, then you switch and you say, "okay, if I have something akin to

an analog model of this kind, I can represent non-linearities, second, third, and fourth order interactions in a systematic way, but I don't know what the hell I'm doing in the way of estimating." So, I guess the hope is that by trying a little bit of patchwork, if you're an optimist, you come out with the best of both worlds, and if you're a pessimist, you come out where you were with the worst of both possible worlds.

ETON: There's a question about what direction funding should go with regards to modeling. If one is willing to go to amoebas of models, it must be demonstrated ahead of time that there's some value in doing that. Admittedly the approach is, you know, to go with an LP approach which may be based on material balances, simple modeling data or econometrics, but there are great limitations. But when you're trying to add a systems dynamics model and an input output sort of component to it, and break down sectors and states, there's got to be some demonstrable advantage. Now, in the discussion so far yesterday and today I have gotten the vibes that it's nice to keep building, but I'd like to try to get some notion as to what the distinct advantage is. Is anything useful coming out of the second generation or another generation of energy models?

HOFFMAN: That's the research task. You tend to mix up the development of models for immediate operational purposes and the research for exploration of some of these directions. Unfortunately, to get funded to do research, we are forced to explain how this great new system is going to be useful in six to nine months. You've got to make a clear distinction between the research component and the applied component.

KAUFMAN: It's a very important issue that he is raising here. And one very simple answer is "does it predict better?" (For example, a backward prediction).

ETON: What good does back prediction really do for me, if I'm concerned about a world in which back prediction beyond two years ago is very different from the world today? "Give me 200,000 dollars and believe in me" is not a sufficient justification for wholesale support of large numbers of researchers in different institutions playing their games.

KAUFMAN: I agree with that, but what can you suggest other than a test on presently available empirical data of the predictive capacity of a model? You certainly want some kind of intellectual paradigm that leaves you comfortable with the basic assumptions in the model and the way that it fits in the real world. But that's not empirical. That again is an article of faith.

HOFFMAN: And that's not the only other area or the most important criterion. Again, prediction of past circumstances where certain policy actions were important is not the criterion for a predictive model for the next ten years for a very different situation.

UTSUMI: Two years ago, the economists at Wisconsin simulated the Japanese economy very precisely from 1920-1935. But they could not simulate the economy after that point.

VERLEGER: You actually have two questions. One, how large should your portfolio be; and, secondly, should you diversify, given your portfolio size, to a number of institutions for separate pieces of research, or go in for one very large integrated model. And I don't think that there's any real answer. Each one of us has his own evaluation of the way he would take that strategy.

BREEN: The basic fact that comes out of this is that we do indeed have different methodologies that we can look at. Each one of these methodologies in turn has its weaknesses for the particular task to which it is being applied. The reason for any marriage is for some complementarity. So, we are looking for the strong points of each methodology where it may contribute best to policy analysis. A model itself is just simply an abstraction from reality. We're trying to get closer and closer to reality and yet keep the information down to some useful level where we can make some analysis. So we're looking for the strong points of each one of these methods and seeing if in some consistent manner we can marry them. It just may turn out that we cannot find this consistent wedding, but this is in itself a need for research. We're also asking can we do it, or is it feasible.

ETON: One of the purposes of this conference was to get guidance from all of you who know much better about how to model than some persons who sit around desks in Washington and play with telephones and typewriters. In the discussion, everyone has been extremely gentlemenly with one another about the ways in which one can go about evaluating which type of modeling is useful, and the intrinsic limitations of what they try to do. I think it's possible to predict inherent limitations of any marriage of models for certain situations. These sorts of things have not been explicit all the time. There's an occasion when it surfaces. The problem is not just our needs. There has to be a clear payoff in order to even go to the R and D stage. There's got to be some reason for enlarging, for getting more detail. How does one go about evaluating when and where to invest?

BENENSON: The nature of R and D is such that there never is a clear payoff evident beforehand.

HUDSON: Possibly for your purposes another criterion is to investigate the range of policy issues which can be handled by these models. You look at a model and you look at a proposal and come up with a good methodology which is necessary but is not sufficient. Does it permit you to ask new types of policy questions that you were not able to ask before?

ETON: What do you mean? In other words that's just a general statement. The notion of econometrics provides us with the opportunity of asking certain types of questions we couldn't ask with an input-output model. The notion of input-output also does things like that. What sort of things are on the horizon of the marriage of input-output with certain econometric approaches? In other words, go beyond the stage of notions and be explicit about methods and what they can provide.

UTSUMI: You have to know what the nature of each methodology is and for what. For instance, I studied the marriage of systems dynamics with linear programming. Linear programming is for decision making which in my case is for immediate decisions. One must know the advantage of each methodology and the problems that arise in marrying them.

HOFFMAN: I can give you a specific example. I developed a technology assessment model which has been used in the evaluation of new technology, and it's been good for that purpose. There is much technological detail, but, without having elasticities in the model, some of the economic assumptions that come out of the assessment are not quite consistent. So there is a need to put more economics into that model. On the other hand, the econometric models have a lot of good economics in them but no technological detail. You can't insert an LMFBR or electric cars and say what the effect is on the economy. So the engineers and technologists do their planning on the technologies and the economists plan the economy, but currently, they're going in separate directions. I think there's a need to bring these two together so that economists can recognize the impact of technology on economic policy, and technologists can see the effects of economic policy on the need for certain technologies. A tight coupling may not be required; it may be a loose coupling with certain consistency checks between the two. There is a clear need, I think, to bring those two together.

ETON: That's a very good start. But then one can also raise the question, what about the behavioral research? What's its role?

HOFFMAN: I think that's the basic research of it. It's hard to define the payoff there. We've got to do more in that area and I can't say that such research would be successful.

ETON: What should be the notions that ought to be looked at?

GLASSEY: May I give you a for instance having to do with systems dynamics? I noticed in Figure 2 of your petrochemical model that there's a little box labeled "Pollution Oppositional Movement." Input to that is volume of pollution and outputs from that are things like expansion, new site locations, and so on. Now, I think there is a behavioral research problem in the question of how one measures something called "Pollution Oppositional Movement". How does one model the value of that variable as a function of the inputs, and how does one model the effect of that variable, however it's measured, on the other decisions? Now the fact that it's in the model gives me a bit of an uneasy feeling because I am not quite sure myself how it might be measured or how it might be transformed by these other variables.

UTSUMI: The people's movement is an intangible. We discussed it many times and came to the conclusion that we must find out the complaints submitted to the local government. When the number of complaints decline, then the capital investment will start to increase. This is one way to represent such an intangible problem. If you start to program in that way you can determine where to go to find data for use in behavioral research.

HOFFMAN: In laying out a research program for such a model, I would think that would be a very important first step—to determine whether you have the ability to use behavioral research and quantify such a parameter. Because if it turns out you can't, then there's no sense putting the model in.

UTSUMI: People start building data banks containing much data, and they don't know what to do with it. They can use statistical regression analysis. But, in this way, they can pin down where the most important data is. Data collection is very time consuming and costly. For the petrochemical study, we could do only a few literature surveys to predict our results in our petrochemical study.

GLASSEY: Let me suggest that one reason funding agencies have more uneasiness about funding research in models than they do about other kinds of research is that they perceive there is very little payoff for past investments in models. I suspect that one reason is that

models are a little more difficult to transfer among the members of the modeling community than the results of physics are among physicists. This is because models tend to be very complex, encapsulated in computer program that may not always be documented to the highest standards. And if we pretend to be scientists, one of the things that we ought to be able to do is to cross check each other's results, but in the modeling game that is very difficult. So I think that maybe the modeling community is now feeling the backlash of its own previous individualistic, entrepreneurial way of going about things. Models tend to be very much proprietary.

VERLEGER: It's too bad Bill Hogan isn't here because as the impresario of the Project Independence quantitative analysis, he has had to face up to this issue of how to marry 27 different models of energy demands and five different models of energy supply. They've at least come up with an initial answer. It's not a terribly satisfactory one, but they're pushing the thing together in terms of marrying the models in a very low cost fashion. Instead of trying to combine all the basically insurmountable computer code, they are doing it in terms of first derivatives and solving out the differential equations.

SPARROW: Is it a matter of marrying models or marrying disciplines?

GLASSEY: We have talked about marrying disciplines in the sense of marrying engineering, technologically-oriented models of the type developed at Brookhaven with econometric models. So there is a marriage of disciplines problem there.

BREEN: But that's accepting a discipline as it is presently perceived rather than perhaps redirecting the educational process that brings about the opening up and combining of disciplines. Once you start getting technologists and economists together, redirection can occur as a natural evolution.

GLASSEY: What we're missing is the behavioral scientists who might give us some predictive models for individual and group social behavior, not only on the demand side but on the strike, riot, revolution, and voting-the-government-out-of-office side!

UTSUMI: One thing that is especially important for energy modeling is that we are anticipating very new forms of energy sources. We will first use domestic oil, then imported oil. By that time natural gas will be depleted. Then we will use oil from tar sands, nuclear and solar energy and possibly other forms. This new technology introduction in the future will become very important for modeling to take into account this sort of behavior.

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The following is a summary of the remarks made by Dr. Utsumi during his prepublication review of the proceedings. Ed.

There are a few more things I want to comment on about collecting and marrying information and models from many countries: 1) The collection of information and models should be distributed among as many countries and experts as possible. The technological way to accomplish this distributed responsibility is to use global computer networks. 2) Most models and the data that must be collected change often. Besides the difficulties of adapting the models and data into a central model and computer system, the maintenance and updating by the specialists at the central location may become obsolete before the data becomes available for analysis. Distributed simulation and data bank systems with the use of global computer networks operated by experts in each field and country represents one possibility for resolving these difficulties. 3) Collection, maintenance, updating of information (and/or models) and the decision-making based on them require close coordination among experts of various countries. This close coordination can be accomplished effectively, economically and instantaneously by the parrallel use of a computer conferencing system on global computer networks.

THE USE OF ECONOMETRICS TO PROJECT ENERGY DEMANDS

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SUMMARY

Verleger presented a critique of econometric techniques for projecting energy demands. He also discussed the usefulness of these techniques for analyzing policy. The pairing of modeling techniques with specific problems is necessary if projections made by econometric techniques are to be accurate. During the last five years most of the econometric projections have been at a very agregated level and price impacts have been systematically excluded.

A subset of these studies was mentioned which have the following characteristics: 1) a specific sector and fuel was examined, 2) the model was regionally disaggregated, 3) price was included as an explanatory variable, and 4) attention was paid to the theoretical structure of demand. A model with these characteristics may, given proper projections of exogenous data, function as a good forecasting tool.

An important difference between the two model types is that the disaggregated model attempts to distinguish between the energy usage pattern and the capital stock of energy-using devices. The stock-flow separation was discussed in detail and a model was sketched that incorporates this distinction. This model allows for extra-market constraints on the choice of fuel, such as the unavailability of fuel in a particular region. Such a model can be used under the situations prevailing today. Price effects and regulatory constraints can be included. Several drawbacks of this model were also discussed. The problem of data disaggregation by fuel, industry, and region was explored.

* * *

Paul Craig has put two very extreme propositions before us. In proposition 1 he states,

> "Events of the past year have introduced major discontinuities in energy prices. Now that this has occurred, previously used projection techniques may be applied. Econometric estimation equations remain unchanged, save for substitution of new values for current and projected prices. Demand elasticities and cross elasticities remain unaffected."

To establish a debate he makes an alternative proposition, totally contrary to his first, by stating:

> "The dramatic events of the past year have projected the national and the world energy system into new and uncharted territory. Previous modelling and projection experience is at best a hazy guide to the future. Public perception of continuing change in the energy sector has irreversibly changed consumer and investor psychology, thereby vitiating all previous estimation techniques. None of these techniques should be used for policy analysis until such time as new methodologies are developed."

These two opposing propositions are useful as a point of academic discussion. However, for industries, whether private or public, who must spend billions of dollars over the next ten years in the expansion of capacity for the production of electricity, for refining of petroleum products, and for expanding the capacity of coal output, the issue seems to be far simpler. It can be stated as follows: whereas much investment planning in these industries in the past has been based on trend extrapolations of demand growth, future expansion must be based on the best obtainable projections of demand. Such projections must, in the current circumstances, evaluate the price and income (or output) responsiveness of demand. The problems are particularly severe for industries in the energy area due to the large capital component in output and due to the very long time periods required for the completion of capital expansion projects. In such circumstances they have no alternative but to rely on modeling.

If econometric modeling techniques must be used for the projection of energy demands in the current situation, the question then becomes which technique has the highest probability of projecting accurately. This paper addresses that issue. Due to the

number of alternative projection techniques which have been published and discussed recently, only econometric models are discussed here. We attempt to evaluate each of these econometric approaches in terms of its usefulness for addressing broad scale national policy questions and more micro level industry-type questions. Three important conclusions emerge from the analysis. First, as one would expect, no one model will meet all the needs of the policymaker and planner. Second, although econometrics can still be used to forecast, the necessary models have not yet been estimated to properly do the job--even though the data are available. Finally, more interestingly, probably the state of the art in terms of econometric modelling of energy demand, at least in terms of the present situation, dates to the 1962 publication of the Fisher-Kaysen (5) model of electricity demand. All models of energy demand published since that date which have come to our attention seem to be at least one step behind Fisher and Kaysen.

The pair of modeling techniques with specific problems is necessary if projections made by econometric techniques are to be accurate. Specifically, we have identified two important problems: demand projections and policy analysis. In forecasting demand we envision the need to simultaneously project total energy demand, supply, and prices along with the fuel mix, use of fuels by sector and purpose, and to calculate import requirements. In the analysis of policy issues, a different set of priorities arises. Given a base case projection of demand, it is necessary to evaluate impacts of alternative environmental, energy, or political decisions on total demand. At times one may want to evaluate the impact on the economy, and hence on total energy demand, of specific policies affecting the energy sector.

These two problem areas distinguish the major uses of econometric models of energy demand. In the discussion that follows we evaluate the most appropriate techniques and the most successful application of these techniques to the evaluation of each of these problems. Because the problems are separable, we examine in Section I the best techniques for evaluating and projecting energy demand using econometric forecasting methods, while in Section II we examine the most appropriate techniques for studying the impacts of energy policy. Section III presents our conclusions.

I. TECHNIQUES OF PROJECTING ENERGY DEMANDS

Until the middle of 1973 all energy forecasts made with econometric models to our knowledge were at a very aggregated level. Examples of these are the work of National Economic Research Associates (NERA) in 1972(11), the U.S. Department of Interior in 1969(15), the U.S. Department of Interior in 1973(14), and the National Petroleum Council's projections (NPC) made in 1972(12). In each of these models demand was treated as a function of real GNP, personal income, manufacturing production, or some combination of these variables. If demand was disaggregated, and in some models it was treated as just a total, the disaggregation only went as far as the four basic sectors—household and commercial, industrial, transportation, and electric utilities. In all of these models there is a unifying thread. Price impacts are systematically excluded. Generally the price elasticity of demand is assumed to be zero. In the present circumstances such models must be rejected for forecasting purposes.

Throughout the period of the 1960's, however, an intensive modelling effort on the demand for energy was undertaken by several econometricians. Most of this work was not designed for forecasting although there is no reason why most of it could not have been used for such purposes. Examples of such work are the aforementioned book by Fisher-Kaysen (5), the seminal efforts of Balestra and Nerlove (2), and the recent efforts by Mount, Chapman, and Tyrell (17). Each of these works deals with the demand for energy in the residential sector. Fisher, Kaysen, Mount, Chapman, and Tyrell, have all studied electricity demand, while Balestra and Nerlove have examined natural gas demand. All four works are tied together by four underlying factors. First, each model studies a specific sector of demand for a specific fuel rather than examining the demand for energy within an entire sector or studying the demand for a single fuel over all sectors. Second, the models are regionally disaggregated. (This is a condition which is probably required of any model that is a candidate for forecasting in the present circumstances.) Third, the models include price as an explanatory variable. Fourth, a good deal of attention is paid to the specific theoretical structure of the demand equation. Finally, all of the models could implicitly forecast demand at a state level for the particular energy resource examined, although none have been used in such a manner. However, in work on the demand for gasoline, Professor Houthakker, Dennis P. Sheehan, and I have used this approach to forecast consumption with a surprising degree of accuracy.

While the aggregated models almost certainly will fail as forecasting tools, the disaggregated model will, given proper projections of exogenous data, work as a forecasting tool, because the structure of these models is designed to resemble consumer decision patterns, to

include price, and to be disaggregated by fuel, by consuming sector, and by region. Thus they could project accurately energy demands during the 70's in spite of the drastic change of prices which has taken place recently.

The most important difference between the two model types is structure. Ideally one wants to separate stock and usage patterns. Neither the aggregate nor disaggregate models do this. However, the disaggregated models do attempt it.

A. Stock-Flow Separation

In the current circumstance the more detailed the disaggregation, the more likely it would appear that the forecast variance or uncertainty would be minimized. The most important types of separation to be made, in our view, are those by region and by utilization. Regional disaggregation is required to compensate for differences in relative fuel prices, weather, and availability of fuels. Separation of fuel or energy utilization from the acquisition of energy using capital is also required at this time. Specifically, it seems necessary in the current situation to examine separately the consumer fuel choice of heat source from the decision on the level of utilization. In the present circumstances dynamic models such as the ones developed by MacAvoy and Pyndick (10) or Houthakker, Verleger, and Sheehan (8), which combine the stock and flow decisions, seem susceptible to forecast error due to possible changes in the rate of equipment acquisitions. An example illustrates this point. Consider first the poor fellow saddled with an electrically-heated home in northern-most Maine. He has no choice of alternative fuel (only the very lucky few with heating systems which can use oil or gas and who live in areas where both gas and oil dealers accept new customers really have a choice). Electric heating systems effectively lock the homeowner into that fuel. His only decision variable, short of selling the home, is to turn down the thermostat. Thus his utilization as well as the more general U.S. electric heat demand equation should reflect the fact that there are a number of electrically heated homes, and their demand can be adjusted only by adjusting the thermostat. Demand then would be a function of weather, the number of homes, and price.

To analyze this problem more precisely let us specify a simple stock and usage equation model for the household sector. Let K_{it} represent the stock of fuel-using equipment for a specific fuel (i.e., heaters and appliances) for gas, I_{it}, the increment of new equipment added in time, t, PG_t, the price of gas, PO_t, the price of oil, and PE_t, the price of electricity. Assume a given percentage, ρ, of all equipment is replaced every year. Then the stock of equipment, K_{it}, is given as

$$K_{it} = I_{it} + (1-\rho)K_{it-1} \tag{1}$$

while additions ΔK are given by

$$\Delta K = \rho K_{it-1} + I_{it} \tag{2}$$

In an economic model which separates stock and usage, net additions might be made a function of new housing starts, fuel prices, and perhaps the cost of alternative appliances, P_{Apl}.

$$\Delta K_i = f^1(PE_t, PO_t, PG_t, P_{Apl}) \tag{3}$$

In this stylized model the demand, Q_{it}, for fuel is then determined as a function of the stock of fuel-using equipment for fuel i, perhaps weather, W, income, Y, and the price of fuel. Usage should not be determined by the price of other fuels, due to the impossibility of substitution.

$$\frac{Q_{it}}{K_{it}} = f^2(p_{it}, Y, W) \tag{4}$$

It is fuel usage that one is after in projecting energy demand. By separating the stock and usage equations one can develop models which allow for noneconomic constraints on the choice of fuel. Specifically, it becomes possible within such a model to examine the rate of growth of households using natural gas under the assumption that natural gas is available to all demanding it, and then to project the actual demand for natural gas after imposing a restriction that households in certain regions of the country will be unable to purchase natural gas due to the well-known supply induced constraint. Also along similar lines, a model specified as in equations 1 to 4 can incorporate the observed dichotomy between the choice of fuel by builders and the desire by homeowners to choose another fuel. This decision process, followed by builders, whereby only capital costs are minimized and not the present discounted value of operating plus capital costs, determines the choice for many homeowners. It cannot be captured in the most aggregated models even if they attempt to formulate demand in a general equilibrium utility maximization form. In summary, the model of demand which separates out the stock and utilization equations would appear to be usable even in the current circumstances. In such a model higher fuel prices affect the utilization of appliances and heaters in the current period, thereby reducing demand, while changing relative prices affect the long run future demand for appliances and burners. Also it becomes possible within such a model to correct for limitations on supply of certain fuels, such as

natural gas, which are due not to market but to regulatory forces.

There are, however, two problems with the specification of the model as described above. First, it is not clear where conservation fits into this model. Higher prices presumably cause utilization rates to fall, but the addition of insulation or other fuel conserving capital is not implicitly included in the model. Second, many of the authors which have fitted such a theoretical model have not estimated both stock and flow equations but have tried instead to use a distributed lag model to combine the incremental addition to stock with the utilization equation. It seems to us that in the current situation these distributed lag models have a much lower probability of succeeding in forecasting energy demand than do models which separate the stock acquisition from the rate of utilization. This is particularly true in models where utilization rates have been assumed to be price independent (Balestra, Nerlove, MacAvoy, and Pyndick). Often this assumption is required. The inclusion of a lagged dependent variable in the distributed lag model will probably bias the forecast upward in the presence of sharp price changes.

The stock-usage equation approach can also be applied to the industrial sector and transportation sector demands for fuels. In these sectors the econometric demand projection would presumably improve as disaggregation increased. Specifically, it seems much more likely that demand for fuels in the industrial sector can be projected accurately at the two-digit level or the four-digit level rather than at an aggregate level. The work of Anderson (1) seems to bear this out. Again it is important to give emphasis to the problem of separating usage and equipment equations rather than trying to treat the problem as one. But more importantly, in the industrial sector, it seems important to maintain as much disaggregation between sectors as possible. The reason for the need to maintain as much disaggregation as possible should be clear. A shift in the demand for metals between the nonferrous and ferrous metals industry can conserve or utilize a phenomenal amount of energy. Industrial demand ranges from 1.5% of output in the leather industry to 17.2% in primary metals. Clearly in projecting the demand for energy in the industrial sector, the structure of the model must take account of this strong difference. Any model which attempts to estimate the demand for industrial energy as an aggregate without compensating for changes in the mix of industrial output must assume that the shares between different industries are constant over time, or that the ratio of energy to output in each industry is proportioned.[1] In such a case one might as well drop econometrics in forecasting input-output modeling.

The projection of transportation demands for fuels would also seem clearly amenable to the stock utilization rate approach, although again it has not been used. For instance, in the personal transportation sector, where most of the demand is for gasoline, it is clearly important to evaluate the stock of automobiles, the average rate of fuel consumption by this stock, and the utilization rate of the stock. For short-term projection purposes (where short term covers a period of less than five to eight years), combination of the stock-flow approach may be good enough here. But for long-term projections, it is clearly necessary to evaluate the demand for automobiles and the demand for gasoline simultaneously. Fortunately, work along these lines is well on its way to completion.[2] Other transportation demand for fuels, that is distillate by truckers, jet fuel by airlines, and fuel by railroads, can clearly be treated in the same way. However, here, some attention must also be paid to the demand for transportation modes and substitution between modes of transportation. Most of this analysis has been completed.[3] One need only merge the transportation demand analysis into models of transportation demand for fuel.

The final sector of energy demand which must be considered in a well-structured energy econometric projecting model is the electric utility sector. Here again the stock and utilization model is important. Specifically, even the simplest econometric model must represent the manner in which utilities fill base load and peak requirements. The model must separate out demands met by hydro and nuclear capacity from demands met by fossil fired capacity. The stock and utilization approach is most important for examining supply from hydro and nuclear sources. In fact, the projection of output from these two sources in any model, be it econometric or programming, will probably be based on the anticipated utilization rate and capacity for each source at any given period of time. The consumption of fossil fuel by electric utilities to fill the remaining demand (both base load and peaking) should be a function of the generating capacity which can use that fuel, the utilization of that capacity, and, where appropriate, the possible substitution between fuels given relative prices and fuel availability. Again, this stock-flow approach has not, in general, been utilized.

B. Price Impacts

The second difference between the very aggregated models mentioned at the start of this section and the more detailed models which have been developed is in the inclusion of price effects in the latter

class of models. The inclusion of such variables should seem so necessary as to go without comment. However, the aforementioned works by the U.S. Department of Interior (14), NERA (11), and the NPC (12) have all basically excluded price effects. And, as we noted above, this makes them useless as econometric vehicles for projecting the future.

C. Disaggregation by Sector and Fuel

The third distinction between the aggregated models and the other models is the separation of fuel demand by sector and by fuel. This distinction, which is required to examine fuel utilization rates, is necessary because the capacity to shift from one fuel to another fuel is limited in most sectors. In fact, as we learned during the embargo and the ensuing reaction period, it is even limited in the electric utilities sector where it had been assumed that there were some substitution possibilities. It is certainly possible to model this, and some authors have even done it, although no one has yet really modelled successfully the way in which industry and households shift between fuels through the acquisition of new capital to replace or augment existing energy-using capital.

D. Regional Disaggregation

The final major difference between the older aggregated models and those approximating our desired target, is in disaggregation by region. Such disaggregation was first taken by Fisher and Kaysen (5) and followed by Balestra and Nerlove (2), MacAvoy and Pyndick (10), Erickson, Spann, and Ciliano (4), Houthakker, Verleger, and Sheehan (8), and others. There are several reasons for the need to disaggregate regionally. First, fuel availabilities differ by region. Thus even in face of very large price changes consumers in some regions cannot shift from one fuel to another. Prime examples of this are the demand for natural gas, which has been unsatisfied for the last several years in the midwest, and the recent experience of utilities in the northeast, who were unable to shift to coal even though their plants had been originally designed to use coal. Other reasons for the need to disaggregate regionally result from the proximity of major fuel consumers to the source of fuel, the variation in the design of urban areas depending on the region, the weather in the different regions, and the age of capacity in the different regions. Location is an important long-run factor in projecting fuel demands because many large users of energy have chosen sites adjacent to or on top of major resources and thus have tied themselves permanently to a guaranteed source of the fuel. The design of urban areas is also very important because some areas are amenable to mass transit systems while others are not. Movements by population between such areas will affect long-run trends in energy consumption (especially long-run trends in gasoline consumption). Weather differences between regions are important in the very long run inasmuch as population movements from colder climates to warmer climates will clearly have a further effect on energy use. Finally, higher fuel prices increase the rate of depreciation on existing manufacturing plants. Since existing capacity is in the northeast whereas new capacity is more rapidly being constructed in the southwest and other warmer climates, energy consumption will be reduced due to retirements. All four of these issues are indirectly or directly tied to the movement of population. Such movements may not be captured by an econometric model directly but once they are imposed on it, more accurate projections of energy consumption can be made. This has clearly been shown to be the case for gasoline; it is quite obviously the case for natural gas and probably for electricity.

In summary, it is possible to project fuel demands using econometric models even under the conditions of the current very high prices of oil. However, it should be clear that the models to do this have not yet been developed except for natural gas, electricity, and possibly gasoline. The conditions under which econometric models can be used to project energy demands with some degree of certainty are, first, that the models be disaggregated by region, by fuel, and second, that the models distinguish between a capacity to burn a specific fuel in a specific sector and the utilization of the fuel given capacity constraints. Finally, within the industrial sector, consumption functions for fuel should probably be estimated on a two-digit basis due to the different possibilities of fuel substitution and fuel requirements. Further, the estimation of fuel demands on a two-digit basis allows for the evaluation of substitutions between materials and between industries due to changing relative prices which result not only from higher or lower fuel prices but from costs of other inputs.

II. The Use of Econometrics to Determine the Implications of Policy Decisions.

The second major area of use of models of energy supply and demand is that of policy analysis. In general, the types of policies considered by these models are taxation, environmental, supply limitations, or energy usage. The taxation types of policies considered have historically involved resource extraction. Environmental policy analysis has concerned the impact

of more stringent environmental regulations on the demand for energy and the demand for capital by sector or by region as restrictions on different types of pollution have been introduced. The analysis of supply shortage using econometric or other economic modelling techniques has centered on the impact of Federal Power Commission regulation of the field price of natural gas, which has reduced the supply of natural gas below the level demanded, and the analysis of the impact of the Arab embargo on the economy. Finally, energy policy analysis has concerned the determination of impacts of regulations restricting the use of energy, end use allocation of fuels, and price regulation. In the analysis of the impacts of certain policies the forecasting models discussed in Section I probably offer the most desirable framework. However, in the analysis of certain other policy changes a different class of models is required. This type of model must be of a more general equilibrium type and must fully reflect the indirect impacts of policy changes as they permeate through the economy. It is especially important for the evaluation of Project Independence.

Forecasting-type models can be useful for policy analysis of consumption-type taxes and the evaluation of energy usage type restraints such as target consumption levels for automobiles or petroleum allocation programs. In the case of consumption taxation these models would treat the tax as a price change. Thus the utilization equation and the stock adjustment equation would both, over the long run, predict a shift in the fuel mix depending on the type equation for automobiles which reflected the acquisition of automobiles, and the use of gasoline per mile of the average automobile would be used to capture this impact. In each case the forecasting model would project the shift in demand due to a specific tax on a given fuel. An example of this is the work of Sheehan and myself (16) in the examination of alternative fuel economy taxes. However, these models provide only the quantity and energy usage calculation due to a policy change. They do not allow for the calculation of the second and third round affects as they permeate through the economy.

For more general analysis of energy policy decisions, a general equilibrium-type framework is required. Candidates for such analysis are the input-output techniques, programming techniques, such as those used by Hoffman (7), and the blend of econometrics in input-output developed by Jorgenson. Only the final item can be considered an econometric model. For the purposes of policy projections the Jorgenson-type model is probably preferred. To be used as a policy-analysis tool, however, the model must first be benchmarked to a reasonable energy demand projection developed by models discussed in Section I. Once the model is benchmarked it probably provides the best tool for analyzing the impacts of different types of energy policies. We make this statement for the following reasons. First, the model provides an accounting framework for evaluating the flows between sectors by any individual sector as a response to price changes. Thus as petroleum prices go up, one can study the substitution of non-petroleum products for petroleum products in the agriculture sector, in the manufacturing sector, and in every other sector of the economy. Second, the model is preferred to an input-output type framework because it directly allows for the incorporation of price elasticities in the demand equation. (In fact, the input-output coefficients are also a function of price.) As we noted above, shifts in relative fuel prices will logically cause shifts in relative fuel demands. Only an econometric model can capture such substitutions using historical relationships. Fourth, the Jorgenson-type framework is amenable to the analysis of the second and third round impacts of taxation or other regulation policies. Finally, by using the input-output type framework, the Jorgenson framework also allows one to evaluate the impact of environmental type constraints which cause fuel demands to be increased above economic levels. Each of these issues has been covered in depth by Jorgenson at this conference so I will not belabor them.

There is, however, a great deal of difference between model concepts and execution. The Jorgenson model requires a demand data set which represents the input-output flow of the U.S. economy annually in current and constant dollars for the period of estimation (1947 to 1971). Such data have not been collected. However, a small 9 X 9 table was constructed by Faucett Associates using trend extrapolations. This provided a means of testing the concept. Jorgenson and Hudson (9) now report that the concept works. This does not mean the model should be employed for policy analysis at this point without confirmation from simulations with other input-output models which have been constructed with real data at a more disaggregated level. In fact, the Jorgenson approach is probably precluded from use until such time as sufficient data on historical flows between specific sectors are collected. It is especially important that the flows between two or three digit manufacturing sectors be collected so that the two manufacturing sectors now included in the model (petroleum refining, and other manufactured) be modelled individually. Until such development is completed, the model requires the assumption that each industry is characterized by the same production function (see footnote

1) estimated on a very incomplete data set.

There are at least two other Econometric models developed for analysis of the impacts of policy on demand. The more well-known is the MIT Natural Gas model which was developed by MacAvoy and Pyndick. The second is TERA (Total Energy Resource Analysis) model developed by Decision Sciences and Mathematica. We can only discuss the MIT work, however, because the builders of TERA have not chosen to offer their efforts for traditional evaluation by their peers. The MIT Natural Gas model was developed to evaluate the effect of Federal Power Commission regulation of the field price of natural gas. It is regionally disaggregated to 18 supply regions and 15 demand regions. Price effects are evaluated throughout the model. In principle it meets all the criteria listed in Section I with respect to forecasting models. However, it may be useless for either forecasting or policy analysis for two reasons. First, the demand equations are stock adjustment types. They fail to separate equipment acquisition from utilization.[4] Second, the authors ignored ten years of econometrics literature when they estimated their demand equations (specifically, they ignored the work of Balestra and Nerlove).[5]

The stated purpose of the model is to examine unsatisfied demand for natural gas due to price controls established by the Federal Power Commission. The authors examine the potential demand which would have occurred between 1966 and 1970. A shortfall in supply of 14% is indicated and is attributed to artificially low prices. The model is simulated under alternative FPC regulation price policies to determine the optimal strategies for clearing the market.

This is precisely the type of design for a policy model. Unfortunately, due to the careless choice of estimation techniques for the demand equation, and due to the highly arbitrary specifications of the demand equations, the model is of questionable use for policy analysis. The specific problems result from the authors' specification of the demand equation. As was indicated above (see footnote 4), they assume utilization of gas appliances is price independent once a fuel equipment selection is made. Further, they assume fixed depreciation rates. In the context of large price increases that we experienced recently for oil and of the authors' proposed increase for the wholesale price of natural gas, such an assumption appears incorrect or at least inferior to the stock-flow approach suggested in Section I. However, even if it were correct, the authors fail to take account of estimation restrictions imposed by their model when they implement it. Specifically, the inclusion of a lagged dependent variable with pooled cross sections of time series data imposes certain estimation requirements which are not met. Thus, according to tests by Nerlove, their parameters are biased. This seems to be a rather unfortunate situation for a model designed to analyze policy.

III. CONCLUSION

Three conclusions can be drawn from this discussion. First, correctly structured econometric models can be used to forecast energy demands and analyze policy issues even in the current circumstances. Second, few if any of the models developed to this date meet the structural criteria required to forecast in the current circumstances. Finally, with respect to the problem of policy analysis, there is a single model which offers, at the present time, real possibilities. It is, however, limited both by data problems and by aggregation problems.

FOOTNOTES

1. This can be illustrated by the following. Let E_i be the total amount of energy required in industry (i) with toal output (value added), Q_i. Assume Q_i is measured in constant dollars while i is measured in Btu's. Then total output for n industries is given by

$$Q = \sum_{i=1}^{n} Q_i. \qquad (5)$$

While total energy demand is given by

$$E = \sum_{i=1}^{n} E_i = \Sigma a_i Q_i \qquad (6)$$

where $a_i = E_i/Q_i$.

We stated above that analysis at aggregate demand in the industrial sector requires either an assumption that the a_i's be constant over time (and thus independent of price), all move in proportion, or be equal. If they all move in proportion, then the value of a_i at time, t, is a constant value of the base period $a_i(o)$ regardless of i.

$a_i(t) = b\ a_i(o)$ for all i.

This would be the case if the price elasticities of fuel demand for the ith industries production function were equal to the price elasticities of all other industries. It also requires, in general, that the other parameters of the production function be identical. (See Fisher (6)).

2. See for instance Chase Econometrics (3), or Verleger and Sheehan (16).

3. See Quandt (13).

4. Specifically, MacAvoy and Pyndick assume that usage of natural gas appliances and heating is independent of price; only the equipment acquisition is determined by price effects.

5. The model is estimated using ordinary least

squares, using regional constants, and a lagged dependent variable. Balestra and Nerlove (2) and others have shown that this is an inappropriate technique for estimating models specified precisely like the demand equation used in MacAvoy and Pyndick.

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SUMMARY OF DISCUSSION

The experience of using two modeling approaches (economic and engineering) to cross-check results was mentioned. This appears to be an attractive method for model validation. Agreement between two models may not be necessary, but the differences sometimes point out omissions, inaccuracies, or ways for improving one or both of the models.

Sources of data for fuel substitution in appliance usage were mentioned. They are the national Home Appliance Manufacturer's Association, General Electric, and Merchandising Week.

Several applications of econometric models were discussed. Econometric modeling of energy demand can be used by utilities for capacity planning. It can also be used to describe a situation after a major perturbation, but before a general equilibrium has been reached. This constitutes medium term forecasting. If an econometric model of the type outlined by Verleger were updated at three or four year intervals, it might be applicable for fifteen to twenty years. Econometric analysis can be used to determine, in isolation, the demand for a fuel such as gasoline. The result could then be fed into a macro model of the economy to determine the effects on the economy of different gasoline taxes. A major regional dislocation of oil supply can not be programmed into an econometric model before the event occurs. Its effects could be analyzed after the fact by a sensitivity analysis. The mathematical programming models can include this type of event through the constraints.

Two conceptual difficulties of econometric model building (specifically, errors in the model structure and method of estimating) were discussed in terms of several problems. These problems are: 1) dealing with price variables when block rate structures exist; 2) estimating the unknown covariance between an underestimated price elasticity and the income elasticity, and 3) coping with indeterminancies resulting from piecewise linear budget constraints.

DISCUSSION

HUDSON: I wonder if you can combine the stock-flow and the static type of model by making the desired capital stock-flow adjustment and having the quantity a function of the capital prices?

VERLEGER: Certainly. This is a more complicated model that one could estimate but nobody has ever done it. At least I have hunted long and hard in the literature. In fact, one also wants to make the depreciation rate a function of the price of energy because as energy prices go up, inefficient capital depreciates more rapidly. We had that experience in November when gasoline prices went up. You saw a movement of used car prices down. They're coming back up but not to the same level. It has given us the first real test of that sort of hypothesis.

HUDSON: You mentioned two approaches. This brings to mind what we've been doing with the Ford Foundation, examining the potential for saving on energy. We churned through the input-output model to find out what the effects would be. Engineers were looking on a process basis, taking into account saturation levels and all this sort of stuff, to find out much of the same thing. It happens that we came up with the same answer. This seems to me a pretty attractive approach for many things; to have two approaches and to make the acceptance of either conditional on the fact that they're both set up in a similar sort of estimate.

McCALL: Nobody suggested what you do if they don't agree.

HUDSON: Get different engineers!

VERLEGER: We have a separate model that runs off the DRI macro-model which projects out the Bureau of Mines detail as a function of prices. We find that our 1985 numbers are about the same, but our numbers between now and 1985 are different. We initially found out that there was no oil going to the electric utility sector with the Hudson-Jorgenson model. When we went back and thought about it and looked at the refining capacity for the total residual fuel available, given their oil numbers and given our oil numbers, we came to the conclusion that residual will be used by electric utilities. Probably the implication is the relative price between residual and other fuels will shift over the next ten years, residual becoming cheaper percentagewise relative to crude oil than it has been historically. But it gives you a framework. You don't expect them to agree. It gives you some way of benchmarking your analysis before you go into testing things like BTU taxes or other policy questions.

Now, another example of this sort of problem is one that Prof. Houthakker has developed for world

petroleum flows. You look at demands and supplies in each region; then you solve the thing using quadratic programming. It's a very small model, but it suggests that, given some moderate price elasticities of demand, and almost zero price elasticity of supply, the long run price of crude oil has got to come down unless Saudi Arabia is basically willing to continue pulling back its price or reducing its production. There's a feasible way of getting to this solution, and that is for the Saudis and other Middle Eastern countries just to hold the price of crude oil at the nominal price it's at now and let inflation reduce it relative to other goods. It becomes a kind of testing and consistency check.

HUDSON: What data is available on use of different fuels for different appliances?

VERLEGER: It turns out that EPRI started thinking about this. The National Home Appliance Manufacturing Association has kept good data on shipments for a number of years. GE and Sears Roebuck are very good sources of data on saturation. Everytime you buy an appliance and send in the card for your warranty, you're registering an item in their data bank in terms of whether you replaced it. It may not be perfect information, but it gives a much better set of information than what utilities have done. The alternative source for saturation data is the Merchandising Week Studies which are turned out every February. They go out asking utilities: "What's your saturation percentage?" and those can vary very randomly.

I should add that one other reason for developing this sort of a modeling framework for utilities is to discover whether they're overplanning capacity. It's necessary to go back and regionalize it and look at the demand growth, to examine their cash flow positions, and to examine their needs for their planned additions to capacity. It looks right now as if their capacity expansions are based on 7 percent rate of growth. If Ed's right, or others looking at price elasticities are right, there's going to be roughly a ten to fifteen percent excess capacity by 1980 in the electric utility industry. This has implications for their rates. They have to pass that on in the form of higher rates because the utilization rates are lower, and/or go to peak-off peak pricing of some sort. This will lead to some serious situations before regulatory commissions.

UTSUMI: You mentioned that there was a disallocation of oil from the South to New England. If you knew such a phenomena could have happened, could you incorporate that into your model, beforehand? In such a case, do you program and disperse the results or do you let those people interested in transportation come to you to program?

VERLEGER: There wasn't a program last November when the problem happened. It was a question of really trying to see what was available to move the oil. I'm probably not the appropriate person to speak in detail about that. In the programming approaches that Houtthakker and Kennedy have developed, as well as Deam at Saint Mary's College in England, you can incorporate that directly as part of a programming constraint. Then you can examine whether or not you have the shipping capacity to handle the problem or you have shadow price if you don't.

UTSUMI: Beforehand, even Deam doesn't know where such a shortage would occur.

VERLEGER: No. What it becomes is a sensitivity analysis task such as what would happen if the Suez Canal is opened? Given the world price elasticities of demands, if you can believe them, what would the price of world crude shipping be in about 1990? It looks like it will be fairly low. Many large tankers are on the ways, and the world crude oil demand is leveling or shrinking. What I suggest is that, whereas it's now $1.90 for a barrel of crude from the Persian Gulf to New York City, it will fall back down to 70 to 85 cents, which will be the long run marginal cost for moving crude oil.

KAUFMAN: Parenthetically, there are well over 400, about 490, tankers of over 150,000 dead weight tons presently on order.

VERLEGER: Yeah.

KAUFMAN: Incredible number.

VERLEGER: But these are like nuclear reactors or airplanes. If they're not actually started, they can be cancelled at some modest penalty. In terms of estimating price elasticities, it's important to worry about the statistical techniques that are used. There are two problems. One is defining price variables where you have a block rate structure. Professor Lester Taylor has done a very useful piece for the Electric Power Research Institute by looking to demand for electricity. The traditional way of estimating a stock-flow function like this, or even estimating a utilization equation, a la Fischer and Kaysen is to use an average revenue variable. That is revenue per kilowatt hour, which is an ex-post price. The typical utility tariff, price per kwh, will slope downward in some fashion and level out. As useage increases, average revenue goes down, and so this gives you a spurious estimate of the price elasticity; in fact, an overestimate. The alternative is to go to marginal

rates such as something taken off the tariff schedule to find out what it costs to consume electricity if you buy the 251st kilowatt hour per month. That gives you the marginal rate by just looking at the slope of the price schedule between two segments, and, in fact, that gives you an underestimate of the price elasticity. It does, however, give you a more consistent estimate because there's no movement. You're always using the same price; it's really the prices for a unit of quantity. Prof. Houtthakker and I took the latter approach on demand for electricity and came up with very small price elasticities and long run price elasticities of about -0.5. There's some work by Mount, Chapman, and Terrell which shows long run price elasticity significantly above 1, using average revenue. The truth lies someplace in between. Probably our simultations with our model using data for 1971 and 1972 (the model was estimated only through 1971) indicate that we overpredicted demand by about two percent. One really needs to approximately double the price elasticity to come up with a model that would forecast accurately.

The other interesting thing is that we simulated this model for 47 different states. We had five states where we underestimated demand growth, 42 where it was over.

KAUFMAN: You have to double elasticity to get an accurate prediction. There are two possibilities. One is specification error in the structure of the model, and the other has to do with the mode of estimating.

VERLEGER: I think the specification error may be the problem since I've already argued that you want to separate stock and flow effects. The mode of estimating it was error components, which is the procedure that was used by Balestra and Nerlove based on the Monte-Carlo experiments by Nerlove. This seems to have the most reasonable probability of being accurate. I'm not really sure. We've just finished these runs and it's something that we're toying around with.

There's another problem. If you underestimate the price elasticity, there is a covariance between your price elasticity and your income elasticity, and we don't know what the covariance is. To come up with an accurate figure, you have to determine that co-variance. It's a real can of worms. But, again, it is an ominous problem projecting about energy in the United States over the next ten years. During these ten years, the electric utilities will incur the major financing requirements. Also, the major capital requirements for the Alaskan pipeline will arise. Bringing on stream and starting up these new sources of energy will create a high initial capital cost before any productivity comes from them. Somehow, once you can get the dynamics worked out of the system, it will probably move ahead more smoothly.

KAUFMAN: Are the elasticities in this formulation going to be dynamic in the sense of Dale's model? The way it looks now or maybe I'm missing something, is that you are estimating fixed coefficients, in log-linear models.

VERLEGER: No, this is straightforward just for residential demand.

KAUFMAN: For a short time period?

VERLEGER: For short time periods. Consumption, in fact, has turned out to work more reasonably, even over the '47 to '71 time horizon. There is a good deal of problem with the Christianson and Jorgenson demand framework of estimating consistent consumption functions in terms of forecasting.

We've had a very difficult time trying to get the consumption side of that model to work. One of the problems with estimating consistent sets of consumption functions using the Jorgenson model, is the fact that the budget constraint is not linear. If you look at two commodities and you assume one of them is electricity with a non-constant price, where price depends on consumption, it turns out that the budget constraint is kind of piece-wise linear. If you have good number one, which is electricity, and good number two, it will be linear with segments like this, rather than the straight line which you would have if the price of each good remains constant. And that has some ramifications because if I draw these piece wise segments correctly, you get two points of equilibrium and then you have a fundamental indeterminancy. What happens is that there are many goods in the economy that are subject to these two or three part rates. That means that when you start to estimate the consumption functions, where you assume all prices are constant, you have a real question of approximation.

KAUFMAN: Could you expect the rate structure to change in form anyway as you go further out into the future?

VERLEGER: Right. We estimated constant elasticity, and, if you estimate a linear model, there is a direct relationship between the elasticity and the importance of the good in the consumer's budget. But either way, there is a tight relationship between the price elasticities. It's not a two or three parameter function the way it is in the translog production function.

BENENSON: Are you suggesting forecasting in the long run using a model like the Hudson Jorgenson model and then forecasting within a price neighborhood using this model?

VERLEGER: I don't know whether what I've thrown out today and what I threw out in the paper is model in the standard sense of the thing. What I'm doing is suggesting what we ought to be doing since I think that is what Paul Craig is trying to find out. I'm suggesting that in the time space of the last 25 years, we've watched the energy/GNP ratio take a dip, and it looks like it's going to take another dip there. The Jorgenson model or these general equilibrium models are probably very good for analyzing the time paths, given prices in the future, under an equilibrium condition. But the path is not independent of its history, and the system has been drastically perturbed over the last six months; the adjustment period may be as long as ten years. What is needed is some sort of precise heuristic modeling, if you want to call it that, where one counts up air conditioners and automobiles, looks at their consumption characteristics, looks at the utilization rate of these appliances as a function of income and price within perhaps some more consistent framework, and then tries to derive a second time path; then when we get out to 1985, assuming there are no other shocks to the system, translate on out using an equilibrium approach. Now this is trying to blend techniques, not the traditional techniques that we've used for forecasting energy demand. They've just looked at energy GNP and said, well, GNP is going to go up at three and one half percent, energy will go up at four or three percent, without regard to price. I think that price is important. I think one needs to incorporate price within a framework looking at the existing stock of our economy to use energy.

BENENSON: That's medium term forecasting?

VERLEGER: Yes. That's medium in that it's not as complicated as what one worries about in very long run forecasting. You have to be careful, as I said, in estimating these utilization rates. I'm afraid that a lot of models that we've estimated over the last ten years, a couple of models in particular, have been improperly estimated, and I'm afraid that they'll be used for policy purposes.

BENENSON: Doesn't Griffin assert that this method underestimates?

VERLEGER: Well, the question is: this method will underestimate, and the rate of underestimation or overestimation will be a function of the rate of turnover of the automobiles, of change in the design of the automobile, or of a change in consumer preference for the automobile. This is his example. I think that that rate of change will mean that a model of this sort will work for about four years, and continue to work for four years once you remake the forecast. I think that in general a 20 year or a 15 year horizon for this sort of model isn't unreasonable. It takes a long time to turn over the stock of housing; it takes less time to turn over some appliances, but they will have a fairly long lifetime. You may take eight to twelve years to turn over the stock of cars. In California my empiricism is that it takes longer when you put on air pollution standards; I see an awful lot of black license plates with the letters L and M. and I was in high school when they started using black license plates out here. People hold onto an old car if the cost of using a new car goes up. But that's also something that really needs statistical analysis, looking at the rate of turnover and how that affects the forecast, but it can be done.

BENENSON: I thought you mentioned earlier that if you're in the same price neighborhood, then general equilibrium models are appropriate.

VERLEGER: I think that the equilibrium models could be used for forecast now if you remain in the same price neighborhood. This type of approach has more hope when you have a large sudden shift in your price. For instance, if you double the price of coal and look at the need for coal by steel producers over the next three years, what would you do? You would first look at what the effect of doubling the price of coal does to the price of steel, what that does to the demand for steel, considering substitutes such as aluminum, etc., and then having arrived at the demand for coal, go back and look at the technological process by which coal can be conserved; there could be some substitution within your mix of plant and equipment, and derive a demand for coal. Over thirty years you might look at the complete turnover in this plant and equipment for the coal industry. You have to distinguish between the short run problem and short run forecasting, (and short run here means ten years instead of the typical eight quarters) and long run forecasting.

HUDSON: I just want to make a general comment on the method. This seems to me to be flexible in the sense that you can use a model of this form in isolation or it fits nicely into a general macro economic model where you can get feedback. If you want to get a lot of detail, you can just run this in isolation.

VERLEGER: It's worked that way so far in terms of gasoline and electricity. We were involved in some nice research last November on the demand for gasoline; then the crunch came and we got pushed from the academic

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research into the policy kind of questions we were talking about before lunch. There it became a question of running it both in isolation and coupling it back into a macro model of the economy to determine what the effects on the macro economy would be from different types of gasoline taxes. It was interesting to discover that, whereas a BTU tax has very little effect because it's small in proportion, a gasoline tax of about 30 to 40 cents took two percentage points off 1974 and 1975 real growth. This report, I think, is kind of generally circulated by the Council on Environmental Quality. I'll be glad to send it to you.

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ENERGY MODELS AND FORECASTS: A USER'S POINT OF VIEW

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SUMMARY

During the past twenty years, Exxon has employed the forecasting methods of judgment and trend extrapolation. Energy demand forecasts for the individual units of the company were accurate, but forecasts for the total industry were low. This may reflect the forecasters' bias not to overcommit the company to grow and not to call attention to the possibility of a loss of market share. Exxon's projections of the world energy supply indicated a flattening out of world oil production in the late 1980's or early 1990's. This alerted them to the energy crisis and enabled them to adapt to it internally.

Currently Exxon uses a linear program for the world oil industry. It is highly disaggregated by geographical region, refining technology, transportation technology, and type of oil. It is used to forecast future oil prices and to provide a framework for facilities planning. It is not a short run model. Another linear program for the short run incorporates facilities constraints. The Wharton model is used with a great deal of judgment to trace the impacts of oil shortages.

The important components of an ideal energy model were outlined. Functional demand (that is, demand for the goods or services provided by energy) should be considered first in an energy model. Price, alternative supply technologies, fuel substitution, and the natural resource base also should be considered. Further, there is a need for disaggregation in order to incorporate these considerations and to monitor changes in trends. However, the disaggregation should be hierarchical so that the model builder can condnese his results and communicate them to the policy maker. Short term energy models should be linked to economic models.

No all-purpose model is expected and it is not useful to criticize a model for not being all purpose. The Brookhaven model is useful because it deals with functional demand, alternative supply technologies, and interfuel substitution. Its hierarchical structure renders it useful to policy makers. It does not deal with the resource issue and at this point it lacks price effects. It is not closely enough linked to economic models to be useful in the near term. Kaufman's model appears to be a commendable approach to a difficult problem. It could be useful for the analysis of oil company data. The Hudson-Jorgenson model lacks enough technical detail to explain the long term effects it forecasts.

* * *

I'm here to talk about energy models from the user's point of view. I will say a few words about my background and experience so that you can make your own judgments about my biases. I'm an engineer. I've spent 20 years in Exxon Research doing petroleum process development. I've been in Exxon's corporate planning department not quite two years, but I've been interested in thinking about energy in the long run for four to five years, beginning when I was still in Exxon Research. I mentioned this morning one of our experiences in that particular analysis. Peter had asked that I also speak of our own experiences with models. I'll deal with that first in a sort of superficial way, and to the extent that it raises any questions, you can kick it around. Then, I'm going to move from that to some generalizations which are personal and do not reflect official Exxon Corporation position. That should not be inferred. And finally, in a very sketchy way, I will comment on some of the specific methodologies that have been talked about these past two days.

First, our own experiences in energy forecasting. Exxon has been doing something called energy forecasting for more than 20 years, but it's really been oil forecasting. Generally this has followed the methodologies of moderate disaggregation of the demand and judgmental trends extrapolation, and generally it has been rather poor. It hasn't made any difference, but we know why. It didn't matter too much. Our system calls for the decentralized operating companies of the total company to submit forecasts both of the total

industry level of activity and their own level of activity; after many years of experience, someone took the trouble of going back and looking it over, and what was discovered was that the forecast of total industry activity was always low. Particularly, the further you went out in the future, it was always low, but the forecasts for the levels of activity of the individual operating units of the company were correct. They were unbiased and accurate. It turns out that this is an institutional way to satisfy needs. One, not to overcommit yourself to grow and do more business. Second, not to admit that you're going to lose market shares. But that's sort of history. One forecasting study which I just want to touch on is one that we did on a one time basis, looking out to the year 2000 and using an assortment of approaches.

One approach, relatable to the kind of thing Ken Hoffman has done, was tracing energy use from resource in the ground to utilizing device and comparing alternative technologies for doing this, particularly alternative long run future technologies, and reaching some judgments about what may be feasible or conceptually possible to allow the generation of some alternative scenarios. Another important part of that study involved facing up to the ultimate flattening of the world level of oil production. Certainly, no one disagrees, I hope, that it is ultimately coming. We have our own estimates of what the total resource base is and, based on that, we could see flattening in the late 80's and early 90's and a need for the world energy system to change. This didn't really impress people inside Exxon a whole lot. Certainly not as much as we thought it should, but it gave us a period of probably more than a year to get used to the idea before things really hit the fan this past year. So to a degree we had begun to adapt internally and emotionally to this notion before it happened, and I think that this was somewhat to our advantage.

Some of what we do is strictly modeling. We have a world-wide oil industry linear program with very rich detail in terms of geographic breakdown, refining technology, and transportation technology. What we use this for is to move from absolutely arbitrary assumptions about what the future marginal price of the Arab crude may be, into extremely detailed prices for all other crudes and all products from these crudes in all parts of the world. Now, that seems trivial, but it does a great deal to lubricate the thinking processes inside the company. The model is respected as being technically complete. What we do in effect is to focus on the judgmental question of what that future price of oil may be out of Saudi Arabia. Given a planning range for that, we simply have a planning range for facilities planning in the rest of the world. That's the essential use of it, to provide a framework for facilities planning. It is not looked upon as a short run model.

There is another LP that is used in the short run that recognizes actual facility constraints. In addition, on the economic modeling side, we have a direct relationship with the people who operate the Wharton model. We found it useful this past fall in reacting to the question of how the economy might respond to a real shortage in oil input. Used with a great deal of judgment, it turned out to be very helpful. I would give perhaps 75 percent of the credit to the judgment of the guys who put the assumptions in and 25 percent to the model.

We're currently involved in a number of price elasticity studies that are certainly less sophisticated than some of the ones we've heard of here and which, from my own point of view, help us to think about the problem, but they haven't given us any tools that we could base decisions on at this point. One example of this was in thinking about price response in the USA. Our people in Houston tried to surround the problem as sort of a beginning point by working one scenario in which consumer expenditures for energy were assumed to be absolutely inelastic, and another in which they were assumed to have unitary elasticity. Working back through energy input-output tables to what this could mean in terms of industrial use of energy, they found it to be pretty small. In other words, the direct effect was the big one. The feedback on industrial activity was rather small. Then they added to this a much more judgmental estimate of what industrial use might do in response to higher prices. That's the range of our experience.

We have, I think, a definite need to broaden our use of models, particularly to bring in fuels other than oil. I think just one example might illustrate this. The electric power generation in terms of total energy consumption has been for some time the fastest growing component, and our treatment of it has been rather off-hand. We simply had somebody make a guess about what it was going to do. We backed it out of the total energy picture and concentrated on what we like to concentrate on. One of the effects of that is that if we look at three years running forecast—I'm doing this from memory and so it's not necessarily numerically precise, but it illustrates how volatile that segment is in our forecast. Two years ago, what we would have called our 1972 forecast, looking all the time at the decade of the seventies, 1970 to 1980, we had total oil growing at perhaps 6 percent a year and residual oil, mainly for electric power, at about 9 percent a year. This was just extrapolation of trend. A year ago total oil had come down a little, and residual oil was down to about 6 percent. Now this year, total oil is

down a little bit more and residual is at 1 percent. This marching year by year and possibly overreacting to things that go on arises, I think, out of a very imperfect and I'd say unsatisfactory level of understanding of demand in that sector.

We have a project just starting. One of the fellows in our math and systems group has been assigned to do a survey for us of energy modeling and methodologies; also, working with people in our department, he will recommend the direction in which we should be moving. So to that extent my presence here has been helpful directly in terms of our corporate needs.

Now some generalizations on methodology for energy modeling. These are not necessarily comprehensive, but they're ones that I feel are safe. First of all, with regard to what I would call fundamentals, functional demand is the thing to relate to. It is the demand for the services that energy provides. I think that Ken Hoffman's approach is consistent with that. I guess I'm also convinced that if this is ever going to be linked to other measures of economic activity (national accounts or whatever) that we've got to distinguish between the functional demands in the area of personal consumption, on the one hand, and the industrial and commercial uses, excluding the energy sector, on the other hand.

Finally, the energy system itself presumably doesn't exist for its own sake, and simply uses energy in proportion to the degree that it has to supply energy for these other two types of functional demands. Another fundamental, clearly, is that price effects belong in thinking about energy demand. I think also that alternative supply technologies clearly belong in any very long run or even medium term thinking about it. And one thing that we haven't touched on very much, and it is a serious problem is the question of the degree to which one form is substitutable for another. We have a favorite story of the parents of a hillbilly boy who were too poor to buy him an electric guitar so they bought him a kerosene guitar. This sort of thing and the coal fired wooden airplane are among the really unbelievable substitutions we hear about.

Well, the final fundamental that I want to mention is this question that Gordon brought up concerning the resource base. You've really got to get that into the forward thinking. It's extremely tough. The kind of judgments that you have to seek have to be judgments of technologists, informed, educated, trained people, experienced in that business. That's very tough, as we probably touched on yesterday, because sometimes they don't even know what it is that they do. Not even when they're good at it.

The second thing I want to touch on as a generalization on modeling is the need for disaggregation. I think first of all, this is the only way to deal with this set of fundamentals that I've laid out. Second, and not really unimportant, at least from the standpoint of a user in a position of trying to interact with policy or strategy makers, you have to have this in order to monitor what is going on, to know when you've had a departure from expectations and when it's necessary to reassess the strategy or the policy. Finally, on the need for disaggregation, I come back to something else that Ken Hoffman touched on, the need for a hierarchical structure. The need is to be able to process the thing at the level of disaggregation that fulfills these other needs for fundamentals and to be able to monitor what's going on, but at the same time to be able to boil it down, keep it simple, and get the message across the interface to the decisionmaker.

The third and last generalization on modeling has to do with the linkage of energy models to economic models. I'm a strong believer in this, but, intuitively, I feel that it is in near term forecasting that a really close tie is most important. It may be the essence of good forecasting, near term. I think, again intuitively, that in the long run this linkage is rather loose and the kind of playing one off against the other that we've talked about here is very likely enough.

Now, some comments on specific methodologies. I'll start out by saying that no all-purpose model is to be expected. I hope we all agree on that. I think it is a waste of energy to look for one, and it is a waste of time to criticize a model for not being one. Starting with the Brookhaven model, my biases probably come through most. I find much to like about it and very little to take exception to. It seems to me that it deals with the fundamentals on demand. It deals with the alternative supply technologies. The fact that it lacks price effects is apparently being remedied. I can't really be sure, but it seems not to deal with the resource issue. The hierarchical structure really looks good to me. It is clearly not a short-run model and if it were going to be one, I would think it would need a much closer link to price effects and economic activity. I doubt if this would be justified. It just doesn't seem like the right horse to turn to for that particular function.

Moving on to what Gordon Kaufman presented, I really feel this is a commendable approach. If it succeeds, it can't fail to be a real contribution to thinking about resource problems. I certainly encourage you when you're ready to come and maybe we can let you in on some of the secrets.

I don't really have any comments on Jim Griffin's. This seems to me to be just one element of a total kind of approach and one that we certainly are interested in. On the DRI model that Ed Hudson presented, somehow, again, this gives me problems on the technical side. I really like the input-output structure of splitting up the

energy sectors, but then some of the manipulations on the energy sectors seem foreign to me. It seems to raise questions for long term forecasting because an explanation of these manipulations is missing; it's the same one that Ken raised. If you do see these long term effects, you have the need to explain it in terms of the means to do it on the technical side. I guess I would have liked to have heard more as to what limits this or what would be needed to adapt it, perhaps, more to near term forecasting. I really need more time to digest the papers we heard today before even attempting to give back any impression.

SUMMARY OF DISCUSSION

A disturbance such as the oil embargo was not explicitly built into the Exxon linear programming model. Rather, the effects of middle east oil shortages were studied using judgment and scenario writing. Rough supply curves were estimated. Exxon used judgmental Hubbert-type curves and scenario writing to forecast supply and probable price.

It is reasonable to use forecasts based on different assumptions depending on the policy questions to be answered. An example of this is the use of high forecasts for R & D policy and lower ones for investment. However, it is necessary to state explicitly which forecast is being used.

Exxon has both a short run and a long run linear programming model. The long run model distinguishes between approximately 28 types of crude oils, which they nevertheless regard as a gross oversimplification. The short run model includes many more varieties of crude oil. It is concerned with a two year time horizon and therefore is absolutely facilities-constrained. It is used for evaluating types of crude oil relative to each other for purchase, sale, and allocation decisions.

In McCall's judgment, Deam's model used at British Petroleum is too detailed, especially in the transportation section. Exxon uses the Wharton model to determine the effect of supply constraints on the economy, once supply is estimated by Exxon. The incorporation of these constraints in the Wharton model is done on a judgmental basis.

DISCUSSION

KAUFMAN: May I ask a question about Exxon's forecasting for capacity expansion investment? You mentioned that this seemed to be one of the more accurate forecasting mechanisms, at least based on past experience. How does this jibe with those of us who really don't know what goes on in that segment of the industry? We see it as kind of a misdirected forecast, the need for refinery expansion. Then all of a sudden we're stuck here with a tremendous excess demand for capacity.

McCALL: First of all, that was a United States problem. On a world basis, there was sufficient refining capacity. Also you are talking about an episode that wasn't typical of the longer run behavior of the industry. The industry had always been a demand meeter, a filler of demand, even though there were no statutory requirements. There was a recent period of uncertainty and postponement of investment that did develop, and I characterize that as just an episode. But it wasn't as extreme, I think, as has been characterized. There was sufficient refining capacity in the world.

KAUFMAN: It's just locally that we got stuck?

McCALL: Yes.

KAUFMAN: Well, to what degree had the capacity requirements forecast broken down for the domestic United States so that companies like Exxon found themselves in a bind because of environmental suits, location problems, etc., etc.?

McCALL: Look at what happened when the oil import quota was lifted. Refining capacity additions were immediately announced or within a few months they were announced. Nothing happened to the siting problem in the meantime. The siting problem was the same as it ever had been. So, I don't think that was the major uncertainty, although it was one of the excuses that has been put forth. Probably the largest uncertainties were: what was going to happen to the import quota and what was going to be allowed in the way of special deals on refineries in the Carribean? And, it's not to be denied that some of what is known in the industry as firming of prices, would have been viewed as good. To the extent that there was not a surplus of refining capacity that might have happened. So there was a little foot dragging. I don't think the mentality or the idea of

meeting demand ever went away, but there was enough uncertainty that there was at least some foot dragging.

BUDNITZ: Do you have the impression that your experience is typical of the other majors or that there are significant differences among them?

McCALL: Well, there are differences. I find we see the world much like Shell does, judging from positions they take publicly on energy issues. We probably see the world in very much the same way. But there are any number of companies with very different positions.

UTSUMI: Would you expect an oil embargo with your oil model or the level of the crude oil price?

McCALL: Excuse me. Are you talking about forecasting the occurrence of the embargo?

UTSUMI: Yes, and the level of crude oil price.

McCALL: Well, let me try to sketch something for you which may give you some idea on that. When we thought ahead a long way, in terms of our own best estimates of the resource base in the Middle East, we developed a graph like this, with time on the x axis and a volume of production on the Y axis aggregated for the whole Middle East. We were sitting down here somewhere (near the intersection of the X and Y axes—Ed.) with an extremely rapidly rising trajectory, and we carried it forward and drew what have been referred to as Hubbert curves (except we don't call them that, they're just free-hand sketches). First of all, you go to a producing man and say, just how fast could you go out and develop, drill up and install logistic facilities and suck it out of the ground just as fast as you could? You get a curve like this, and that eventually uses it all up. We said, well, nobody would do that because that last increment of facility that was added would only be used for half a year and then you shut it down. So there's some kind of flatness up here at the top. On the other hand, trying to put ourselves in the position of the producing govenment, we sketched some other curves which generally took shapes like these (see figure below), and they are certainly more typical of some of the historical situations, for example, Venezuela, where you can go back and track the shape of this. It comes up to some kind of level and then, looking into the well known reserve/production ratios, added production just doesn't happen. The new production simply comes in to fill in the decline in old wells and you get this very long plateau. The difference in our projections between maximum production and the higher plateau curve is about ten million barrels a day in about 1985. That is a hell of a big difference. So, you feed this back through, and you get the notion that there would be supply problems. Certainly then you wonder what could happen to the price of oil. So we had scenarios. We had this long history of Middle East oil prices, vs. time. We said, well somewhere out here in the Mid 1980's, it seems likely that this will be a supply limited commodity and will need some basis for arriving at a price, other than the fact that you could expand its production. We reinvented the notion that there would be snythetic gas or oil production in the United States from coal. We assumed this might be used as a fair parity price for the overseas oil. We sketched in what we like to call an orderly transition. We even went down to Washington to talk about the country's need for a synthetic fuels R and D program in terms of this orderly transition. What really happened was a sudden price jump instead of the smooth one we hoped for. I don't know if that answers your question. We probably did enough thinking about the future to ask the right questions, but I think we were fantastically naive in imagining that things would be sort of smooth.

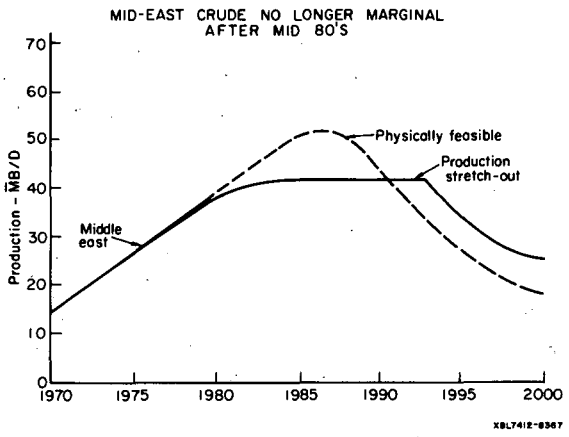

Fig. 1. Middle East oil production scenarios.

UTSUMI: Couldn't we program and model your description into your forecast of this?

McCALL: That'd be great. That's the sort of thing that we may be moving towards.

HOFFMAN: I guess you have been applying different methodologies to projections developed for different purposes. One methodology for investment purposes, and another one for long-term forecasting which presumably some longer term policy action would be addressed.

I wonder if we could talk a bit about this notion that we spoke of yesterday, about the idea of using a

more risk-strategy with regard to R and D development, perhaps taking a higher forecast as the basis for that kind of policy? Yesterday, I interpret, from your remarks that you mean you would agree with that type of philosophy. Tom Sparrow raised the point that isn't it really a most likely projection in any case that you'd want to base all policy on?

McCALL: Well, I'm in closer agreement with your argument, with one reservation. I'm sure you don't mean to suggest it, but I wouldn't want anyone to feel that we were using biased projections. I think we want to be very clear, if we are using a high projection, to call it the high projection and not to say this is *the* projection. One of the great historical examples of this sort of thing is the study that Palmer Putnam did for the AEC in 1952 or 3. Remember that? I think, he really did the right thing. It was basically a judgmental approach, but he never cloaked over the fact that what he was doing was highsiding on demand and lowsiding on resource just to see how bad the problem could be. It turned out, even though he thought he was highsiding, that he just about hit it on the demand side.

HOFFMAN: Then you see a similar view in the Resources For the Future study, but just turned around where they made a case where resources were adequate through the years.

McCALL: If Putnam's study was in any degree determinant in the pace of the development of the atomic power, thank goodness . . .

HOFFMAN: It was the old problem of a projection which reinforces your preconceived notions and your preconceived, redeveloped objectives.

BENENSON: Did you mention that for the short-run you are using other types of forecasts?

McCALL: Well, I can't even guess how many types of crude oil it had in it. Our basic international one has 28 crude oils, which is a gross oversimplification of the variety of crudes.

HOFFMAN: How large is this LP?

McCALL: I should have known that I'd be asked that, but since I don't work with it directly, I don't know.

HOFFMAN: Deam talks about his eight pounds of print-out.

McCALL: Deam's model is overblown, I think. There isn't any fundamental justification for the detail he has, in my opinion.

HOFFMAN: It's something smaller?

McCALL: Yes. We've been aware of BP's activities in that field and we just don't see eye to eye. We really think that at the level we have, we really do what we want to do. I gather that their's is about six to eight times as big as ours.

HOFFMAN: Is it the regional definition primarily?

McCALL: Primarily, but I think his transportation sector is also very, very rich, and unnecessarily so. That is a judgment question, but I guess we've been running ours long enough to feel fairly good about it. The near term model we use is absolutely (facilities) constrained because it's concerned with the next two years. You could say it is a way of evaluating crudes relative to each other for buy or sell type decisions and allocation decisions within an overall lack of enough oil.

BENENSON: How did you calculate the constraints?

McCALL: I don't exactly know what you're saying. You mean the facilities constraints?

BENENSON: Yes. Or is that information you already know?

McCALL: Yes.

VERLEGER: I presume also you can find out about that 7 percent expansion in refining capacity that's been going on over the last year?

McCALL: That should have been put in, although some of that is statistical. But it needs to go in in the actual addition. There's a lot of data known in the industry about that sector. It turns out that that's what oil men, aside from those who go looking for oil, have focused their attention on for years and years. It would have been better maybe if they'd focused some of it on marketing.

BENENSON: Is that available outside the industry?

McCALL: Well, the Oil and Gas Journal publishes some pretty good statistics.

VERLEGER: You break it up by region, and by units of refineries; you can even sit down and draw up your own little regional LP model of refineries.

UTSUMI: The model of Exxon's does not include time dynamics, like Ken's. Is it just a snapshot?

McCALL: No. We run it on a step price basis and it is facilities constrained in the early years. Facility additions are worked out with time, you know, so that

the units aren't torn down by the model after they are built.

UTSUMI: And is this connection to the Wharton development model indirect?

McCALL: Oh, absolutely indirect. First of all, the Wharton model doesn't account for supply, as far as I know. The only way that we were able to manipulate the Wharton model to deal with supply constraints on the economy was, as I said, through the judgment of the guy who runs it for us, and he makes some really good guesses.

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ENERGY MODELS AND FORECASTS: A USER'S POINT OF VIEW

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SUMMARY

One of the main conclusions Breen drew from this conference is that econometrics can be used to complement modeling techniques such as input-output and process analysis to model the total energy system. Once this has been accomplished, as Hudson and Jorgenson have attempted, high priority should then be attached to sectoral and regional disaggregation. This step is needed because policy decisions impact differently on different industries and geographical regions.

A user's evaluation of a model takes into account 1) the policy question to be answered, 2) the level at which the decision will be made, and 3) the cost of the model. Concerning the first point, the policy issues must be clearly stated before the usefulness of a model can be determined. For example, a utility which must consider the issues of rate structure design, facilities planning, siting, and environmental impacts needs a regional model. Such models should be linked with more comprehensive national models, but the methods for doing this are not well developed. A particular problem is whether price determination takes place in the regional or the national model. Further more, once it is determined, by what method can it be incorporated in the model to which it is linked?

A user of models also takes into account that decisions are made at several very dissimilar levels (national, regional, and corporate); no single model can answer questions at all these levels. Finally, the model builder must be able to justify the costs of the model to the potential user. Breen cautioned that models should be applied only to the uses for which they were intended.

* * *

The program has me listed as speaking on energy modeling from the user's point of view. I would like to retitle that to "Reflections of a Potential Model User". Please excuse me if I cannot address my remarks to specific papers or topics, since I have read eight papers in a little over three days. I guess the best analogy is as follows:

> I am standing along the railroad track, a fast train just went by, and I am trying to remember the faces that I saw in the train windows.

So I cannot really say very much with respect to particular papers.

Prior to this conference, I had the impression that aside from several econometric demand models, little progress had been made in the area of energy modeling. Reviewing the literature one finds few references to dynamic, interactive energy models. Moreover, the concept of total energy systems, with both demand and supply interacting in the market place, has not found application in energy modeling efforts - perhaps due to data constraints and lack of interest on the part of policymakers. The econometric modeling efforts mostly have been partial demand models (usually confined to a single sector), single fuel, and took supply exogenously. Attempts at constructing econometric models of supply have been mostly unsuccessful.

From this conference, two important ideas have emerged. First, the narrower methodological tools of econometrics can feasibly be complemented by other modeling techniques such as input-output analysis, process analysis, systems dynamics, mathematical programming, to name a few. An example of such a marriage of modeling techniques has been presented by Ed Hudson. The second idea that has emerged is that the communications gap between the researcher and the policymaker needs to be recognized and eliminated in order to more efficiently address policy questions.

At this point, I would like to make a few overall observations on the conference and then finish with comments on energy modeling and forecasting for policy analysis from a user's point of view.

The progress in energy modeling is encouraging but I hope that the modeling community puts into their programs for future research and development with high priority the following:

1. Disaggregation: Disaggregation should be both geographic and sectoral. National policy analysis cannot ignore the effects of policy decisions on significantly different sub-populations. The obvious is that the welfare implications on sub-populations should be the concern of the national policymaker. On the regional level, disaggregation by sectors is important to weigh policy alternatives. Economic and social dislocations between sectors must be considered when policy decisions are intended to impact a particular sector. The costs of the effects of the policy decision should be equal to or less than the benefits.
2. Total Energy: The policymaker not only wants information on the supply of and demand for a particular energy form, but he needs to know how this information fits in the context of other energy forms. Energy policy decisions are really total energy policy decisions. What might be an optimal allocation scheme for natural gas, might not make sense when also considering the availability of fuel oil and coal.
3. Credibility: The credibility of energy models is as important as the availability. Generally, policymakers are not comfortable with explicitly quantitative models. Many times these same policymakers are not technically trained; they feel that mathematical models somehow exclude the human element or allow no room for "judgment." To some extent there is the feeling that model makers are practicing some sort of witch -craft.

   There have been some bad experiences generated in using models in the decision process, due to their ill-conception or their use in analyses for which they were not designed. One example of such an econometric model in a rate-making proceeding before the Federal Power Commission by the Commission's staff is found in the Permian Basin rate case hearings. The use of the model by the FPC staff misfired due to the model's technical errors and the consequences of this action reverberate to this day. Brave is the regulatory staff that is willing to use anything other than the conventional accounting techniques at a rate-making proceeding today. (See The Use of Econometric Models by Federal Regulatory Agencies, Joe L. Steele, Heath Lexington Books, Toronto, 1971).

   Another aspect of credibility is the "communications gap" between the modelmaker and the policymaker. This point has been explored rather thoroughly during the conference, but I would reiterate that it is important that the analyst seek out and understand the needs of the policymaker. Moreover, the analyst should "educate" the policymaker on the availability and use of quantitative tools to aid decision making.
4. Costs: Closely related to CREDIBILITY in the policymaker's mind is the cost in using sophisticated models. Do the benefits outweigh the costs? There is much modeling activity presently, but how much of this activity is the result of the bandwagon effect? When the policymaker must make a decision, he will rely on the technique for obtaining the information he needs that is least costly.

   Our experiences indicate that policymakers have depended upon judgmental, subjective models for the most part. In the shortrun these models are least costly in dollars. Perhaps, for the private sector policymaker, this is one of the most important points in the decisions on whether or not to use a sophisticated model.

Now I would like to speak as a model user--or potential user. The above general observations are important, but there are some related topics that are meaningful to model users. Most of what I remark on is particularly relevant to the energy industries' uses of models.

The first point involves policymaking itself. At what level is policy being made for which there is need of a model? It is not at all clear that the same models can or should be used at all policy levels.

The power industry, for instance, is involved at three distinct tiers of policy-making--federal, regional (state, local, pollution control districts, etc.), and corporate. Examples of policy questions involving the individual firm at the first two levels include regulation of rate-making, plant siting, pollution control, transmission rights, allocations of fuels, size and degree of integration of corporations. To each of these, the firm may need to react, but in turn will have to consider its own set of policy questions such as rates structure design, whether or not to site an additional plant or to enlarge existing facilities, to take on the additional costs of capital equipment to reduce environmental degradation or to close a plant and reduce production, to accept curtailment of supply limited fuels or to switch to alternative fuels, and to integrate operations for increased efficiency and reduced costs or accept a smaller share of the market. At the corporate level, policy questions revolve around profits, returns to

equity, or earnings per share.

The second issue that the business sector model user is keenly aware of is spatial. Individual firms sit in regional economies and local as well as national and international conditions affect demand for their products. Just the openess of regional economies becomes an enormous modeling problem. It should be noted from the literature and as evidenced at this conference, that most of the modeling activity is at the macro level.

At PGandE we have an energy research program in which we are constructing regional econometric models of natural gas and electricity demand in our service area. These models are highly disaggregated sectorally and geographically and the inter-relationships of demand utilization among sectors is well-defined.

One of the methodological questions that has not been addressed at this conference is the linkages between localized or regional models and national models. A particularly aggravating problem that has appeared when using any existing national model with our service area model is in price determination of energy forms. Due to regional price regulation, the linkage with national models (which aggregate price determinants or depend on exogenously made price assumptions) leads to unrealistic results. That is to say, when the regional model covers an area which is significantly large relative to the area covered by the national model, the question of independence arises. Prices may be endogenously determined locally but the national models tend to also treat price endogenously. To further complicate the issue (and since we are talking about using existing models), the linkages themselves are almost entirely one-way, that is national model to regional model. There is no dynamic feedback. This is more of a problem for the user in that he goes on the market to "buy" this model for one purpose and that one for another purpose from different sources. But this problem does point to the need for modelmakers to also explore the methodology of linking separate but hopefully compatible models on a regional basis.

SUMMARY OF DISCUSSION

The linkage problem is a general one for regional models. Compounding the difficulty is the computational cost involved in manipulating a highly disaggregated multi-regional model. One possibility for reducing computer cost is to isolate the region of interest and aggregate the remaining regions into one.

The interaction between regional and national price was discussed but not resolved. The aggregation of dissimilar industries and the assumption of constant returns to scale and perfectly competitive markets in the Hudson-Jorgenson model was criticized as being too great an abstraction from reality to be useful as a policy model for industry. This approach was used because it facilitates mathematical formulation. In the short run, however, these assumptions may not be too unrealistic.

DISCUSSION

UTSUMI: In answer to your question, from the systems dynamics point of view, there is a very easy way. In a given region, you set up the plant requirements from an engineering standpoint; then figure what it costs for the fuel, what the depreciation is, and so on. It can be programmed in an endogenous way, and the supply can be made exogenous to the California economic model. This model can produce an average price which can be compared to the national average price.

BREEN: There should be some linkage from the regional model back to the national model as in the case that I mentioned, where a particular region is major user of a particular fuel form. The price is then determined essentially in that region. But if we take it as input or as an exogenous variable from the national model, we have no way of going back and adjusting the prices in the local economy.

UTSUMI: No, the national price is just taken as an indication of the average; it is not used actually in the real world. Only the local price of gas or electricity affects the local residents. It's just through comparison that the local price provides feedback to the national price.

VERLEGER: Isn't this more generally the problem of all regional models? It's fundamental. We have never figured out how to cope with them. You run a Wharton or Chase or DRI input-output model over

the country and then you specify it. Only Karen Polenske at MIT has made a heroic effort to regionalize the input-output table. And the problem you run into is if you think about an input-output table of 80 order for every state, you've got to do something with the damn thing. You're talking about an astronomical computer project.

BENENSON: One way around that budget constraint may be to take the area you're interested in, say California, and then aggregate the other regions into one or two. You then have California and the rest of the world. Then you have trade flows going in and out to California which are unchanged by the aggregation. What I was groping with is: how do you feed back any price effects? It immediately occurred to me that a multi-regional input-output model might help. I could see it in terms of flows of commodities, but I don't know what's happening with price.

VERLEGER: What you're saying is, and I think you're right, that rather than forecasting price on the national basis, one wants to have an econometric model that's regionalized so that you have a price determination in each of the regions. In the case of energy, for energy sources primarily localized to the West Coast, it will be determined most heavily in the west, the California sector. But then that gets away from the question of what PGandE does when you are faced with a macro model that forecasts data price and they also have their own price.

BREEN: Well, the consistency problem becomes pretty great when a particular corporation uses a regional model. The linkage is usually one way. You just take in as exogenous variables certain information, but we're not feeding back into the national story the effects that are generated locally.

VERLEGER: The only thing that I can suggest is to do what Ed Villani did for Exxon or what users of models do periodically. That is to get on the model and sit on it until you get it where it's consistent. This is hand forcing the interactions..

BREEN: I'm not saying that there is no solution. I'm saying this is a methodological question that we haven't essentially thought much about yet and one that's approaching very quickly.

UTSUMI: It all depends on how important the factors in the other regions are in determining the price. If there is an important relationship with other regional prices, you have to program in the other prices. Then it becomes a distribution problem.

HOFFMAN: It's a fairly tractible problem from the optimization viewpoint. With a coupled set of regional optimization models, possibly decomposition algorithms could be used to determine what prices to feed back.

BREEN: I guess another question that I have in mind is sort of a methodological question. It's actually not so much a question as an observation of Hudson and Jorgenson's model and its assumption of crossing industrial grouping with constant rates of return, flat supply, and implications of perfect marketing. If you look at the energy industries, these assumptions go counter to what we have observed for the industry. Perhaps in your program of improvements you could sophisticate the production functions to take this into account?

HUDSON: It could be; the trouble is we get a lot of mileage out of that assumption.

BREEN: You get some neat and nice mathematical results, but, if you're looking for something beyond this nice, neat mathematical result, I should say....

HUDSON: Look at the production from a short-run and long-run point of view. In the short-run, you have fixed capacity and constant returns. Then you can install new plants and pop in a few generating stations here and there. I haven't investigated this technically, but I'm not convinced that that assumption is not realistic.

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