MODELING FOR INSIGHTS, NOT NUMBERS: THE EXPERIENCES OF THE ENERGY MODELING FORUM

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Omega: The International Journal of the Management Sciences

EMF PP6.5

August 1982

Energy Modeling Forum
Stanford University
Stanford, California 94305

OMEGA The Int. Jl of Mgmt Sci. Vol. 10. No. 5. pp. 449 to 462. 1982
Printed in Great Britain.

0305-0483 82 050449-14$03.00 0

Modeling for Insights, not Numbers: the Experiences of the Energy Modeling Forum[1]

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(*Received December 1981*)

It has often been contended that the primary goal of policy modeling should be the insights quantitative models can provide, not the precise-looking projections—i.e. numbers—they can produce for any given scenario. Students of the energy policy process, in particular, have noted that preoccupation with the plethora of detailed quantitative results produced by large-scale computer models has substantially impeded their influence on key policy decisions. The creation of the Energy Modeling Forum (EMF) at Stanford University in 1976 represents one potential remedy for that situation. The EMF was formed to foster better communication between the builders and users of energy models in energy planning and policy analysis. The EMF operates through *ad hoc* working groups, composed of national and, more recently, international energy modeling and policy experts. These working groups conduct studies concentrating on a single energy topic. The diversity of backgrounds of the working group members ensures that the language of the EMF studies is English, not computer. Each working group identifies existing models relevant to the study's focus. A series of tests is then designed by the group to illuminate the models' basic structure and behavior. A comparison of results is published in a widely distributed report that identifies the models' strengths and weaknesses in the context of the study's topic. Seven EMF studies have been initiated to date: (1) Energy and the economy, (2) Coal in transition, (3) Electric load forecasting, (4) Aggregate elasticity of energy demand, (5) US oil and gas supply, (6) World oil and (7) Macroeconomic impacts of energy shocks. Each EMF study has broadened the understanding of the nature of the relevant policy issues and the models that have been, are, or could be used to address them. The present paper describes how each study's key insights were developed in the context of a simplified analytical framework that provided the proper perspective for understanding the model results.

INTRODUCTION

THE OIL EMBARGO of 1973 brought economic and political chaos to the oil-importing world. A particularly devastating attribute of the embargo was its unexpectedness. It was difficult for the world's economies to adjust to a sudden reduction in oil availability. In addition, it established a new world order in petroleum which had implications that were enigmatic to almost everyone. The stable conditions that had characterized the world energy system for almost a quarter-century provided neither experience nor incentive for anyone to try to understand its workings very well. During that earlier era, conditions each year were presumed to differ little and in predictable ways from those existing during the previous years.

The unfamiliar circumstances created by the 1973 embargo provided the motivation for the birth of a new discipline known as energy

[1] Occasional paper—EMF op 5.1 (draft 2). Earlier versions of this paper were presented at the Joint CORS–TIMS–ORSA National Meeting, Toronto, May 3–6, 1981 and the Third Annual Conference on Energy Use Management, Berlin, October 25–30, 1981.

policy modeling. Through the use of energy policy models, analysts attempt to capture the essence of important relationships characterizing the energy system with simple mathematical equations. By definition, modeling involves drastic simplification of reality; nevertheless, most energy models are large enough to require computer implementation. Energy policy modeling involves the application of these large-scale computerized systems to the analysis of energy problems and their potential solutions.

Energy policy models have often been employed to provide precise numerical answers to specific policy questions, making the forecasts themselves the important product of the process. Although this process has frequently helped those who construct models to develop a broader understanding of energy policy issues, that information has rarely been transmitted to decisionmakers. Instead, the avalanche of detailed quantitative results produced by the models has often tended to blind model users to the insights they can provide. Many believe there is an urgent need to improve the communication of those insights to the model-using community. Hogan [17] captures the sentiments of those ascribing to this latter view: "it is not the individual results of a model that are so important; it is the improved user appreciation of the policy problem that is the greatest contribution of modeling."

One's perception of modeling's role in policy analysis can greatly influence how one feels models should be evaluated. Sometimes model evaluations have been conducted as technical assessments of individual models and their properties. In this form the activity has involved only technical specialists who are concerned about how the models produce the results they do and verifying that the models produce the results they claim. They also evaluate statistical and other methodological approaches adopted by the modelers.

An additional role for model evaluation emerges when models become viewed as tools more for developing insights than for forecasting numbers. With insights as an important product of the modeling process, an assessment of how the models are used is as important as understanding their structures. Failure to communicate the logic of model results, especially when they are counterintuitive to policymakers, can become a major obstacle in model acceptance [14]. In this context model evaluation becomes a vehicle for communicating to policymakers why the models produce the results they do. In their survey article on model analysis activities, Greenberger and Richels [15] identify two main approaches for evaluating energy models from the user perspective. Both focus on improving communication between model builders and model users. Model assessment, the first category, subjects one model at a time to careful scrutiny. In addition to verifying that the model is technically sound, this process also explores the model's usefulness and limitations over a range of issues. In a second category, forum analysis, the results from many models are compared under common input assumptions. By focusing on a limited set of questions, forum analysis aims at developing insights about (1) why different models sometimes produce different answers and (2) what can be learned from models about the nature of energy problems and their potential solutions. Whereas model assessment improves user awareness of particular models and their potential application to policy questions, forum analysis broadens user insights and understanding of important energy issues as well as of the models themselves. Model assessment is conducted for model users though not necessarily in their presence. The distinguishing characteristic of forum analysis is that model users are essential to the process. The prominent role of model users, however, does not mean that communication is unidirectional in forum analysis. Modelers also share in the broader understanding of policy issues as well as in learning about the structures and behaviors of the participating models.

The prototype for forum analysis is the Energy Modeling Forum (EMF) headquartered at Stanford University. Since its inception in 1976, the EMF has employed over 50 energy models to build insights about six study topics. Over 200 individuals have participated in these studies, another 200 have been observers and over 2000 have received the EMF reports. Thus, the EMF has focused a large amount of resources in a relatively short period on the development and communication of the insights the models can provide. The present paper highlights some of the key points learned by those who have participated in this activity. This review should help provide the reader with a perspective on evaluating energy models through a forum approach with an emphasis on developing insights rather than numbers.

The label 'insight' may appear to be somewhat presumptuous to the reader, who will more appropriately determine for himself the value of the observations discussed here. We use this term to represent how the thinking of EMF working group participants has been sharpened or changed during the process of comparing models within a forum context. Thus, this paper should be viewed as an attempt to share some of the best observations that have been harvested from EMF studies. These observations have resulted from the collaborative effort of many modelers and model users. As participants in this process, the authors are among many who have contributed to these observations.

THE ENERGY MODELING FORUM: AN OVERVIEW[2]

The goal of the EMF is to improve the use and usefulness of energy models in the study of important energy issues. One of its major subgoals is the development of better information relevant to energy policymaking and planning through the use of energy models, i.e. to build insights about selected energy decisions and scenarios. The organizational structure of the EMF facilitates the implementation of a process designed to achieve that goal.

EMF structure

The heart of the EMF consists of the *ad hoc* working groups of about 40 members each. The working group, composed of volunteer participants with a balanced representation of model users and model developers, is organized around a specific energy issue to ensure both the proper representation of relevant models and participant interest in the policy or planning issues addressed. The ideal group is diversified geographically, institutionally and philosophically.

The EMF is assisted by a senior advisory panel. This group, chaired by Harvey Brooks of Harvard University, is composed of senior energy decisionmakers—e.g. utility executives, oil company executives, presidents of energy research organizations, congressmen, and senators—who represent the ideal target audience for the EMF studies. The panel suggests appropriate study topics, helps recruit working group chairmen, critiques the final reports and helps disseminate the results of the studies. Another vital source of ideas and suggestions during all phases of the EMF process are the EMF project monitors at EPRI, DOE and GRI. Those individuals often have active research interests in topics related to the EMF studies and are conduits to many influential policymakers inside and outside of their own organizations.

The overall planning, coordination of daily operations, and administration of the Forum are handled by the EMF staff, supervised by the EMF director. The EMF staff is affiliated with the Stanford Institute for Energy Studies and the Departments of Engineering-Economic Systems and Operations Research. The staff provides support for the senior advisory panel in the development and selection of study topics, recruits working group chairmen, assists the working group chairman in organizing a study, participates both as members of the working group and as staff to this group, and publishes the final working group report. The communication function of the EMF is enhanced by close ties maintained among the various participants in the Forum: the working group, the senior advisory panel, the funding agency project monitors and the EMF staff.

The EMF process

The EMF process begins with a broad call to modelers and potential model users to assist in identifying potential study areas. The various proposals are then summarized by the staff for the senior advisory panel, which chooses a topic and suggests potential working group chairmen. Next, the staff recruits a working group chairman and assists him in recruiting the balance of the working group. Once the working group is established, a period of intense modeling activities is initiated. Model documentation is reviewed, study goals are established, scenarios are designed, model results are compiled and interpreted, and a report is written and published.

[2] For a more detailed description of the goals, organizational structure, process, history, and future of the EMF, see Sweeney and Weyant [24].

The complete process may take as long as two years, involving typically three or four working group meetings spaced about three to four months apart.

For several reasons EMF studies tend to focus on topics that are relevant to broad classes of policy issues, not on specific policy initiatives. First, specific policy initiatives are evanescent; a specific initiative under consideration at the outset of a study may be adopted or discarded by the time a study ends. Second, although the models can provide information relevant to certain dimensions of a proposed policy, they rarely include all dimensions felt to be important to the policymaker. Finally, participants in the working group often belong to organizations that are identified with a certain position on a specific proposal, creating potential conflicts of interest. Six EMF studies have been completed: (1) Energy and the economy [7], (2) Coal in transition [8], (3) Electric load forecasting [9], (4) Aggregate elasticity of energy demand [10], (5) US oil and gas supply [11] and (6) World oil [12]. Each study has produced a number of conclusions in the process of broadening the working group's understanding of the salient dimensions of the energy problem and various energy policies. Only a few of the most consequential results from the studies are described here.

EMF 1: ENERGY AND THE ECONOMY

In the first EMF study [7] the working group examined the effects of reduced energy availability on the level of economic output.[3] The study was initiated in the fall of 1976 as a test of the EMF research concept.

At that time there was wide diversity of opinion about the role of energy in the economy [1, 5, 19]. Those who believed that energy is inextricably tied to the workings of the economy perceived reductions in energy availability as causing significant declines in economic output. Perhaps responding to the much publicized works of Meadows [20], this group cast the energy–economy discussion in terms of the growth vs no-growth controversy with energy as the limiting resource. To that group a 'locked-step' relationship between energy and economic output was axiomatic. Althoug some energy conservation was possible in th view, these individuals generally believed tha new energy supply technologies were the key t future economic growth. At the other extrem were those who believed all but the most sever cutbacks in energy supply could be accommodated through low- or zero-cost conservatio opportunities [13]. In their view a smooth transition into a more energy-efficient societ would occur without significant economic cos simply by creating the correct incentives fo energy conservation. The expense and environmental damage of investments of new supply technologies were not needed in this world view. Although much of the policy discussion represented a much less extreme position [16], it nonetheless reflected the basic controversy raised by these arguments.

The EMF 1 study provided a structure for this debate. The working group viewed energy's relatively low historical value share of total GNP as an inappropriate concept for assessing energy's importance to the economy. Flexibility in substituting capital and labor for energy would influence the future value share of energy in the economy for scenarios with a higher price or reduced availability of energy. Hence this ability to substitute between energy and other factors of production in the economy was considered to be a better measure of the ability of the economy to grow in the face of reduced energy availability. This energy–economy linkage was also influenced by the effect on capital formation and hence on productivity.

The specific processes for energy substitution may be varied and intricate, but the aggregate level of implied substitution between energy and nonenergy inputs to the economy can be summarized in economists' terms as the elasticity of substitution. That parameter is approximately equal to the elasticity of energy demand—the proportional change in energy demand in response to a change in energy prices. For example, if the elasticity of demand is -0.3, the elasticity of substitution will be approximately 0.3 and a 10% increase in energy price will lead to a 3% decrease in energy demand.

This concept, the elasticity of substitution, provides a convenient index for summarizing the aggregate relationship between the energy

[3] This is called the 'energy–GNP feedback' effect.

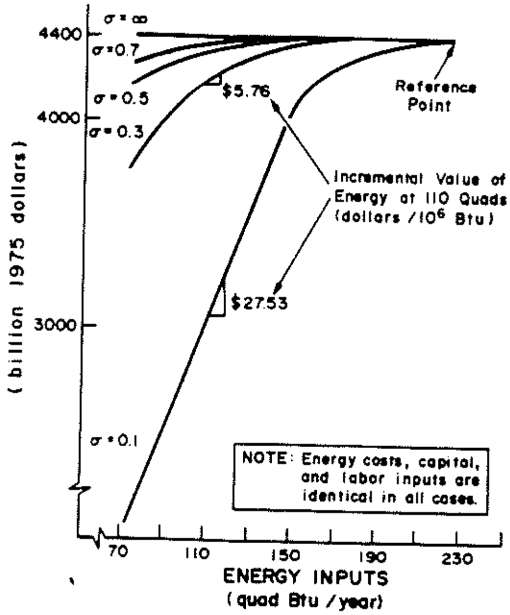

FIG. 1. *Economic impacts of energy reductions in year 2010 for various elasticities of substitution (σ). Source: EMF Report 1.*

sector and the rest of the economy. In fact, as stated in the EMF 1 report:

> "If we assume that inputs of others factors such as capital and labor are held constant, then the elasticity of substitution virtually determines the feedback effect of the energy sector on the rest of the economy." [7]

In Fig. 1 GNP in the year 2010 is plotted as a function of energy input, holding other inputs constant, for various elasticity values.[4] The importance of the long-run elasticity in this context is startling. For example, a 50% reduction in energy availability produces a 28% reduction in GNP if the elasticity is as low as 0.1, but only a 1% reduction in GNP if the elasticity is as high as 0.7.

What do the models included in the first EMF study imply about the magnitude of the aggregate elasticity? Two of the study's scenarios were used to develop estimates of the elasticity of substitution for each model; those estimates are shown in Fig. 2. Both the Kennedy–Niemeyer and the PILOT models, which assume limited substitution, display long-run aggregate elasticities below 0.1 and generally near zero.[5] The parameter in the remaining models, which include detailed substitution possibilities, ranged between 0.3 and 0.5. Figure 1 shows that this range of substitution represents substantial but not unlimited flexibility in energy use.

These efforts provided a fulcrum for further efforts to understand the effects of reduced energy availability on the level of economic output. In addition, the analysis and results of the first EMF study emphasized that the relationship between energy and GNP is neither one-to-one nor is it nonexistent. Interest in the nature of the energy–economy link continues (see, e.g., the discussion on EMF 4 below) but in early 1977, with the unveiling of the new Carter Energy Plan, the potential role of coal in America's energy future seemed a good choice of topic for EMF 2.

EMF 2: COAL IN TRANSITION, 1980–2000

A second EMF working group, organized in July 1977, compared results from 10 different models in the analysis of coal production, distribution, and utilization. The study emphasized the sensitivity of patterns of future coal

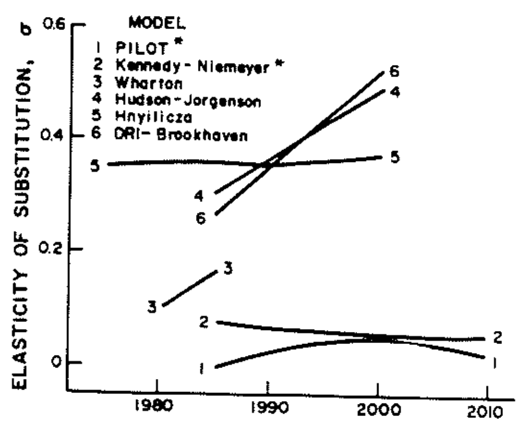

FIG. 2. *Aggregate elasticity of substitution calculated using the outputs for the base case and the base case with constraints. Source: EMF Report 1.*

**Models 1 and 2 have negligible substitution, by assumption.*

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[4] These estimates assume that a Btu tax is gradually imposed to reduce energy consumption. Should a reduction in energy use be the result of an increase in the cost of producing or importing energy, then the GNP effects would be substantially larger.

[5] The PILOT model has been revised to provide the most detailed representation of the energy–economic substitution processes available.

use to changes in regional economic conditions and standards on allowable emissions [8].

The year 1977 marked not only a major shift in national energy policy towards increased coal use but also the first set of major revisions to the Clean Air Act of 1970. The simultaneity of these two events would not be of interest were it not for the conflict of goals they seemed to create. One of the amendments to the Clean Air Act instructed the Environmental Protection Agency to substantially reduce the allowable level of airborne emissions from new electric power plants. Since over 60% of coal use in the US is for electric power generation, the new amendments, which would require the addition of costly scrubbing devices to coal-fired electric power plants, were viewed as creating a significant disincentive to increased coal use. Many argued that the new standards would be particularly devastating to plans to develop the nation's extensive western coal resources. Western coal generally has a sufficiently low sulfur content, unlike eastern coal, to be burned without scrubbing under the old standards but not under the new ones. It was argued that the western coal would need this advantage to justify the cost of long-range transport to the large midwestern and eastern markets. In fact one prestigious group went so far as to contend that the revised standards would probably prevent an expansion in the utilization of western coal [21].

The question of the effects of the revised emissions standards on regional and national coal use was prominent in the work of the second EMF working group. The old standards were included in a reference scenario, and two of the other seven study scenarios considered alternative interpretations of the Clean Air Act amendments. The 90% removal scenario assumed that all new coal-fired power plants would be required to use scrubbing devices to remove 90% of the sulfur dioxide emissions. Alternatively the 1/2 New Source Performance Standards (NSPS) scenario assumed that the power plants would be required to limit SO_2 emissions to 0.6 lbs per million Btu of fuel input in contrast to the old standard of 1.2 lbs per million Btu.

A significant conclusion drawn from examination of the model results was that the new standards, while imposing costs on western producers, would not significantly retard the

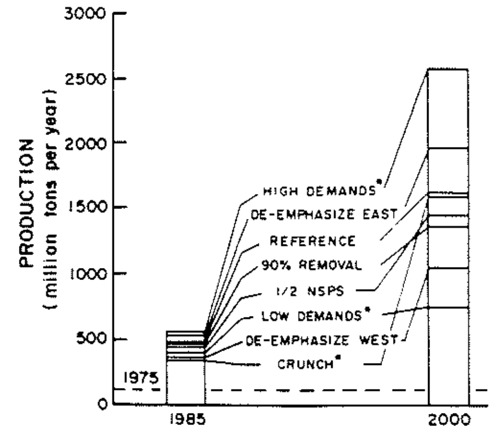

FIG. 3. *Median western coal production projections. Source EMF Report 2.*

**Scenario does not employ the reference level demands.*

move to western coal. Figure 3 shows the median western coal production projections for the different scenarios. A threefold increase in western coal production is projected between 1975 and 1985 and a tenfold increase by the year 2000 for the reference scenario as well as the two scenarios representing alternative interpretations of the new standards—90% removal and 1/2 NSPS. This somewhat surprising result emphasized several points about the economics of the US coal market. Western coal not only has a lower sulfur content than eastern coal, but it is also significantly cheaper to mine. Large-scale surface mining techniques can be used to recover much of the western coal resources, whereas much lower-productivity, deep-mining techniques must be employed in the East. And the lower recovery costs for western coal can more than offset the lower cost of transporting eastern coal to many important midwestern population centers. In addition, some of the increased coal demand is expected to replace natural gas in the south central states where the western coal transportation disadvantage is not as great.

The results of the EMF 2 study identified several central issues that appeared in the debate on alternative emissions standards for coal. The study also considered other dimensions of the future of coal markets, including the major role played by the electric utility sector in determining future coal demand. This latter issue led quite naturally to the next EMF study on electric load forecasting.

EMF 3: ELECTRIC LOAD FORECASTING

The third EMF working group examined results from 10 models that are currently being used to forecast electricity demands. The EMF 3 experimenters identified and illuminated prominent load-forecasting issues and improved the understanding of the models' capabilities and limitations [9].

Forecasts of peak load (kilowatts) and electricity consumption (kilowatthours) are two critical inputs used by electric utility planners to determine the amount, type and timing of additions to electric power generating capacity. Over the past several years disruptions of historical relationships in the electricity market and of trends in the growth of electricity have led planners to develop new, more complicated forecasting methods. At the same time the lead times required for capacity additions have increased substantially since 1970 because of new environmental concerns, greater complexity and larger scale of new generation technologies, and longer regulatory proceedings. As a result planners must look further into an already uncertain future, thereby increasing the possibility of an imbalance between generation capacity and customer demands on the system. If the forecasts overstate actual future electricity demands, excess generation capacity will be built, causing significant rate increases for electricity customers. On the other hand, forecasts that understate these load requirements may cause the possibility of brownouts or emergency purchases of extremely expensive oil generation capacity.

Seven of the load-forecasting systems included in EMF 3 are in active use at some of the nation's largest electric utilities. The other three models project national electricity demand by adding together projections for several regions, e.g. census regions. Methodologically, though, there is a more fundamental difference in the two types of models than a mere summing up of regional forecasts. The national forecasting systems combine historical data from many utility regions to estimate relevant parameters in a demand submodel for a single utility region, whereas the models actually employed by the utilities use only data for their own regions.

The primary advantage of the combined or pooled data approach to parameter estimation is that the effects of a much larger range of values for the independent variables, e.g. prices, can be considered. The primary disadvantage of this approach is that characteristics that are unique to a particular utility region, e.g. climate and demographics, may not receive adequate attention. These differences in the characteristics of the two methods would be academic were it not for the striking differences in results they produce. One of the EMF scenarios investigated the effects of a 10% increase in the price of electricity on electricity demand. As shown in Fig. 4, the models that use cross-sectional data for parameter estimation (ORNL–REDM and Baughman–Joskow) project a strikingly larger price response than the other models that use data from individual utility regions.

As a consequence of these results, strong arguments were voiced in favor of each of the two parameter estimation methods. No consensus was reached on which method is superior, but there was general agreement that the implications and assumptions of both methods merit careful assessment. In the cur-

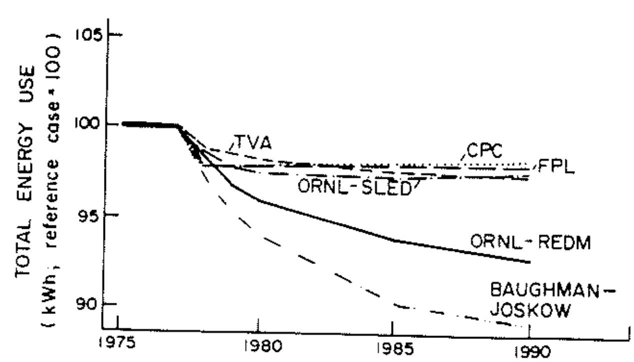

FIG. 4. *Change in electricity consumption projections with 10% price increase relative to the reference case. Source: EMF Report 3.*

rent environment of increasing electricity prices, it is *conceivable* that a number of the nation's major utilities are forecasting load with a method that leads to a systematic overestimate of demand. Such errors lead to the construction of unnecessary capacity at great cost to consumers.

The debate on electric load-forecasting issues will likely continue in the Utility Modeling Forum, which was spawned by the EMF 3 study and is patterned after the EMF but with a focus on issues of direct interest to the nation's electric utilities. As in EMF 1 much of the debate in EMF 3 centered on the magnitude of the response of energy demands to higher prices. The growing appreciation of the importance of the demand elasticity in energy forecasting and planning led to a comprehensive review of the evidence on the value of this important parameter during EMF 4.

EMF 4: AGGREGATE ELASTICITY OF ENERGY DEMAND

In their review of the results of the first EMF study, the senior advisory panel suggested further investigation into the evidence on the value of the aggregate elasticity of energy demand. The fourth EMF working group conducted a specialized test of the aggregate price elasticity of demand implicit in 16 energy models [10].

The first EMF study emphasized the aggregate elasticity as a convenient summary of the energy–economy linkage. A higher elasticity implies less economic losses resulting from a reduction in energy availability or from a change in the cost of imported energy. If energy costs are raised by a domestic tax on energy that keeps the higher energy expenditures within the country, the economic losses become greater as the aggregate elasticity increases [25]. The aggregate elasticity is also critically important for many other analyses, including forecasts of future energy consumption, evaluations of the appropriate timing of energy technology development, assessments of energy tax policies, and predictions of the Organization of Petroleum Exporting Countries (OPEC) pricing strategies. The higher the assumed elasticity the lower will be the forecasted future consumption of energy in high-price situations, the less urgent will be the pc ceived need for new energy supply technol gies and the lower will be projected world ‹ prices.

Although the first EMF study had produc‹ some estimates of the aggregate elasticity, the was substantial interest in expanding tl number of models for which estimates we available and in refining the experiment ar definition used to produce those estimates. Th EMF 4 working group investigated the choic of index, composition of price change, star dardization of aggregate economic activit point of measurement and dynamics of pric change used to produce the elasticity estimates

Two points of measurement were examine during the study: (1) primary energy, measure directly before refining, electricity generation and synthetic fuels conversion losses; and (2 secondary energy, measured directly after conversion and refining losses. During the experiment it was concluded that the secondary elasticities were more reliable. Aggregate elasticity estimates were obtained by (1) varying fuel prices in each model at a specified point of measurement; (2) allowing the model to translate those price changes into changes in prices further downstream, adjusting demands accordingly wherever they are measured and translating those quantity changes back to the point of interest; (3) aggregating the price and quantity changes at the point of interest; and (4) using the aggregate price and quantity for a number of different price changes to compute the aggregate elasticity estimates.

The results of the experiment were more striking than anticipated. In general, the highest implicit aggregate secondary demand elasticities were associated with the more comprehensive models covering all energy-using sectors, incorporating the full range of potential flexibility, and directly utilizing historical data to statistically estimate parameters. Long-run aggregate secondary demand elasticity estimates for these five models ranged between 0.3 and 0.7. Other models produced lower estimates either because they incorporated lower subjectively determined component elasticities or because of the limited scope of energy-use substitutions addressed in the models. Four out of the five comprehensive models in this category produced elasticity estimates in the range from 0.1 to 0.2; a fifth estimate was 0.6.

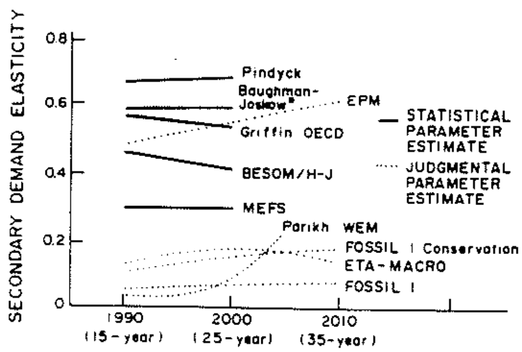

FIG. 5. *Aggregate total demand elasticity estimates. Source: EMF Report 4. Note: The Paasche index was used to calculate these estimates.*

**Does not include transportation demands.*

Figure 5 shows the results for the comprehensive models.

The EMF 4 study, reinforced by the experience of the last two years, helped support the view that the aggregate elasticity of energy demand is surely greater than zero and probably much greater. In fact, many participants revised their own personal elasticity estimates upwards as a result of this study. Despite the central importance of aggregate energy demand behavior though, supply-side considerations are critical for many issues. Thus, the focus of EMF 5 on US oil and gas supply seemed appropriate.

EMF 5: US OIL AND GAS SUPPLY

The fifth EMF working group investigated the dependence of US oil and gas supply on alternative world oil prices, oil price controls, alternative federal leasing rates, changes in the tax structure and resource base assumptions. The study focused on the determinants of the rate of US oil and gas supply rather than on the estimation of the amount of oil and gas that might be ultimately recoverable [11].

The US oil and gas supply group first met in January 1979 at a time when President Carter deliberated on whether to extend or phase out price controls on domestic oil production. This administration had developed a complicated scheme, the Natural Gas Policy Act of 1978, to phase out price controls on natural gas by 1985. The dissension created within policymaking circles by both of these decisions originated in part from the wide disagreement among analysts about the sensitivity of future oil and gas production to higher prices. Those who opposed allowing the prices of domestic oil and gas to reach the equivalent world oil price level cited analysis suggesting that decontrol would not stimulate enough domestic production to offset the large initial costs to oil and gas consumers. At this time there was also wide disagreement about the likely level of oil and gas production during the 1980s and 1990s. This was important for assessing the country's oil dependence and vulnerability to disruptions as well as for understanding the shifting fuel composition on US energy consumption. Projections of oil and gas production by the turn of the century ranged from less than half of the current levels to a substantial increase [3, 6]; the lower levels portend large increases in US oil imports, while the latter would be enough to accommodate increasing US oil and gas demands and a reduction in US oil imports.

Figure 6 shows the range of domestic oil production projections from the models for the high price scenario, which, given the rapid escalation in oil prices during 1979, seemed a better reference than the study's original reference scenario. None of the models projects a cataclysmic decline or a dramatic increase in oil production through the turn of the century. The trend of moderately increasing or declining production within each model results from the long lead time for new supplies and the dominance of reserves that have already been discovered. However, there are strikingly large variations in the projections across models. A large portion of the oil produced during the 1980s will come from reserves that have already been discovered, and there is little disagreement about the rate at which those reserves will be produced. Consequently, underlying the differences in the production projections shown in Fig. 6 must be differences in reserve additions that are much larger. Indeed, Fig. 7 shows that the factor of four differences in cumulative reserve additions (horizontal axis) during the 1980s underlies the factor of two differences in cumulative production projections (vertical axis).

The solid sloping line shown in Fig. 7 represents results from a simple oil production model in which the key parameter is the fraction of the undiscovered resources that are found each year. The numbers shown corre-

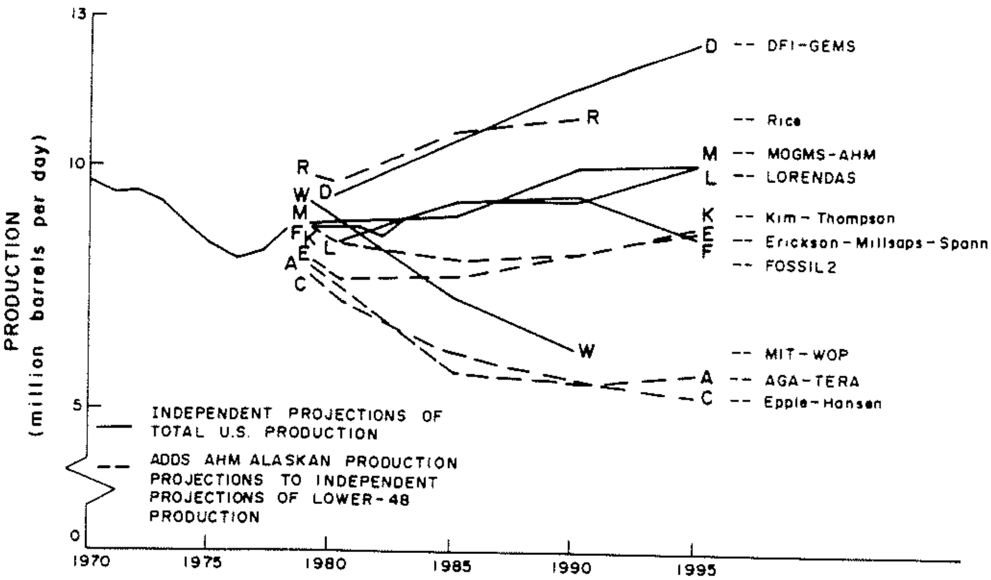

FIG. 6. *US total crude oil production for the high price scenario. Source: EMF Report 5. Note: production excludes NGL.*

spond to values of that parameter or the rate of discovering the remaining resource base. A higher discovery rate leads to more cumulative reserve additions during the 1980s given the geologic availability of undiscovered resources. When combined with a constant amount of cumulative production from existing reserves, this variation in new reserve additions creates differences in cumulative production from all reserves. The bottom portion of Fig. 7 shows for reference purposes the average *level* of cumulative reserve additions for the 1950s, 1960s and 1970s. Although past discovery rates remain relatively constant, the average level of cumulative reserve additions declines over this three-decade period, reflecting the declining base of undiscovered resources over time.

Observe that some of the models project discovery rates during the 1980s that exceed the 0.02 to 0.025 rate observed for the 1950 to 1979 period, while others project rates below this historical one despite much higher prices. These differences do not necessarily indicate the superiority of one projection over another. Each model incorporates certain assumptions on how prices, policy constraints, and geologic conditions influence the economic climate for expanding the reserve base.[6] The advantage of the simple production model is its ability to place the widely different results of the participating supply models within the context of historical experience. Although the figure does not identify the causes of the discrepancy in the

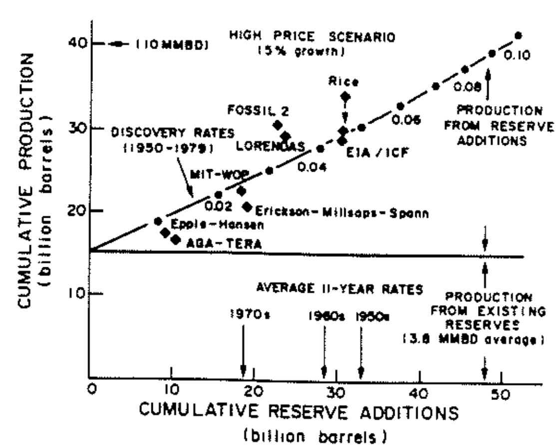

FIG. 7. *High price scenario projections vs simple model results: 1980–1990. Source: EMF Report 5. Note: simple exponential model. (Undiscovered resource assumption: 77 billion barrels.)*

[6] While the models generally indicate that higher prices will increase production, a higher rate of increase in the expected future price leads to ambiguous results, depending on the nature of the economic incentives incorporated in the model. Thus, the normal concept of price elasticity of supply seems difficult if not impossible to apply correctly to a depletable resource like oil or gas. To some extent the critical issue may be when oil and gas will be produced rather than how much in the aggregate will be produced. For this reason the working group chose not to display price elasticities of supply as a summary measure of the responsiveness of supply to higher prices.

expansion of the reserve base, it raises the issue of why the discovery rate should vary so widely across models, particularly given its historical stability.

The range of projections for US oil and natural gas production implied considerable uncertainty about the country's future dependence upon oil imports. Since decisions by domestic oil and gas producers are only one of many factors determining its oil dependence, the Forum turned its attention to an analysis of world oil trends. This shift in topics marked a more explicit interest in international energy issues by US analysts and policymakers.

EMF 6: WORLD OIL

The sixth EMF study began in January 1980, at a timè when interest in the world oil market was at a peak. The study was designed to investigate the implications of variations in several key parameters and policies on world oil supply, demand and price [12].

Entering the 1980s there were marked disagreements about future world oil prices and the levels of oil consumption and production. The uncertainty in these trends reflected to a considerable extent the rapid reversals experienced in the world oil market during the 1970s. The initial OPEC oil price shock was followed by several years of stable nominal prices. These conditions tended to breed optimism about future world oil price increases. This view was reinforced by several factors indicating a possible breakdown of the cartel: the emergence of a two-tier pricing system within OPEC in 1976 and discussions about an oil glut that continued until late 1978. At that time OPEC decisions to curtail production were followed quickly by the complete stoppage of Iranian oil. These conditions, compounded by speculation on the part of oil consumers, led to a dramatic rise in the real price of oil. This change in world oil market pressures brought a more pessimistic view of future energy trends. Talks of breaking the cartel were replaced by concerns over how rapidly world oil prices would rise above inflation. The answer to this question depends significantly on the interaction of several important factors, including OPEC oil production ceilings, the crude oil demand elasticity, import reduction programs and future levels of production from alternative energy sources. Thus, the stage was set in early 1980 for an interesting and informative study of world oil trends projected with a number of major world oil models.

By far the most striking result of the study was the long-run trend of progressively higher oil prices for the next 40 years. This upward trend, however, can be expected to vary over the time horizon. Through the early and mid-1980s the world oil market may remain fairly slack, with prices increasing rather gradually or even decreasing. Beginning in the late 1980s and continuing into the first decade of the twenty-first century, oil prices are projected to increase more rapidly. Within the first two decades of the next century, lower assumed economic growth rates coupled with increases in the supply of nonconventional oil dampen the rate of increase in oil prices. Only during the early years, and then only in some scenarios, is the real price of oil projected to decline. World oil price projections for the reference scenario are presented in Fig. 8. Even more revealing, however, is Fig. 9, which shows continually increasing prices in the optimistic scenario. This occurs despite the rather heroic assumptions of increase in OPEC production capacity, a major breakthrough in the technology of alternative energy sources and a very successful OECD-wide oil import reduction program.

The general upward trend of prices results from projections that oil supplies will grow more slowly than world economic activity. Even considering the delayed demand adjustments motivated by the pre-1980 price increases, world oil demand can be expected to grow more rapidly than supply if prices remain constant. Therefore, world oil prices must continue to rise, slowing demand growth and increasing oil supply so as to clear the world oil market. Alternative energy sources will help moderate the price increases in later years, but they will not be capable of capturing a sufficient share of the market to reverse this price trend. Moreover, these price trajectories could be made worse for the oil-importing countries by a major oil disruption, which could bring oil prices to over $100 a barrel for the duration of the interruption.

Projections of rising world oil prices led to discussions of whether oil-importing countries should implement strategies to reduce their

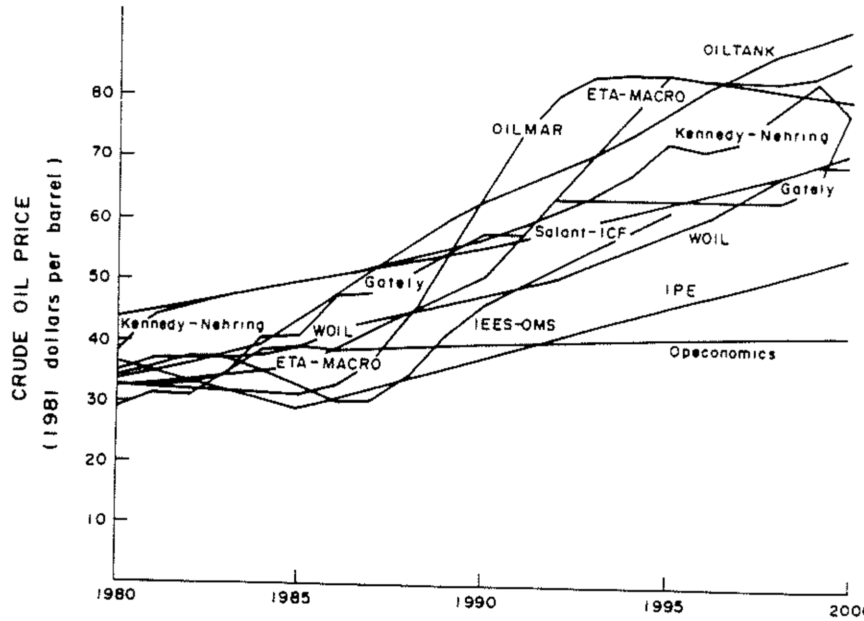

FIG. 8. *World oil price projections for the reference case. Source: EMF Report 6.*

purchases of petroleum imports. Measures to reduce oil imports can yield significant economic benefits to oil-importing countries by (1) reducing the growth in future world oil prices and (2) reducing the economic losses during supply disruptions. Benefits of import reduction, expressed on a per-barrel basis, are collectively described as the oil 'import premium'. It represents the additional charge above the world oil price that importers would be willing to absorb in order to be less dependent on world oil supplies.[7] Various values have been assigned to this oil import premium for the US ranging from nonexistent to $35 a barrel.[8] From exercising the 10 different oil models over several different scenarios, the study con-

[7] The concept parallels the 'optimal tariff' argument in the international economics literature.

[8] This range of estimates refers to what is termed the 'monopsony' or market power component of the premium that arises from the fact that reduced import demand may lower world prices. Although most authors provide a wide range of values for the premium, higher estimates can be found in [23] and [22] and lower estimates in [2] and [18].

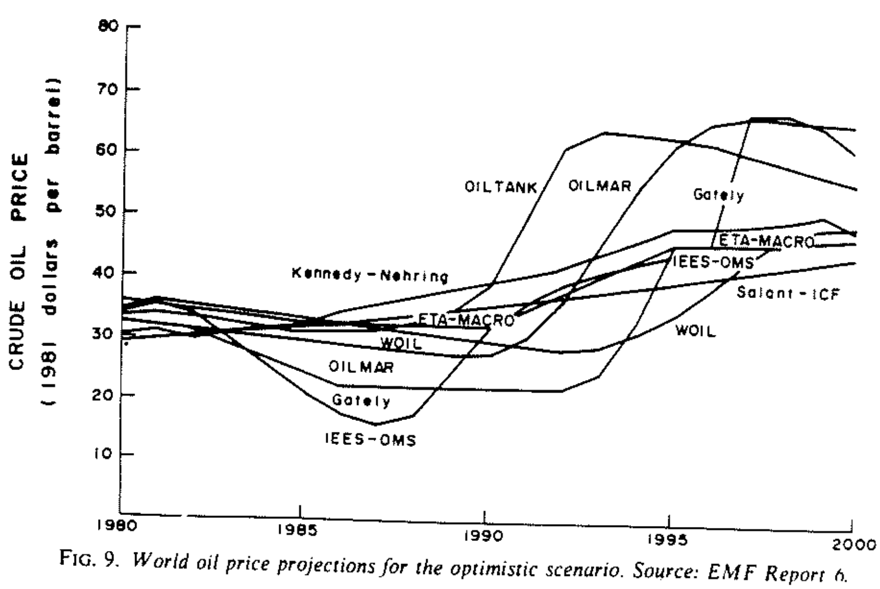

FIG. 9. *World oil price projections for the optimistic scenario. Source: EMF Report 6.*

cluded that the oil import premium for the US would be slightly under $10 per barrel. Thus, while this is not as high as that estimated by some, it clearly shows that public policies for reducing oil imports may have some economic justification.

FUTURE EMF DIRECTIONS

The likelihood of the world economy being jolted by a third major disruption in the international oil market in less than a decade has increased considerably with the growing political instability in the major oil-producing regions. This generated great interest in the disruption scenario analyzed in the EMF 6 study. Although most of the models projected large effects of a 10 million barrels per day capacity disruption, many projecting an initial world oil price increase of $100 per barrel or more, the maximum prices and the pattern of price adjustments over time varied radically among the models. In part, this disparity of projections results from the fact that many uncertainties—stock building and release patterns, expectation formation, and exporter behavior—have yet to be characterized. In addition, however, the models of that study did not represent many of the ways by which the world economies have adjusted to higher prices in the past, e.g. unemployment, inflation and allocation rules. The international oil models of the previous study leave us with a very simple understanding of why disruptions are a serious problem and only some notion of how to cope with them. Understanding the full range of adjustments to sudden price changes for developing specific policy responses requires the results from more detailed short-run macroeconomic models. This led to the senior advisory panel's selection of macroeconomic impacts of energy shocks as a topic for EMF 7.

EMF 7 examines the near-term implications of energy shocks on such aggregate economic indicators as inflation, economic growth and unemployment. Large macroeconomic models and several smaller energy–economy models with short-run emphasis will be examined in order to delineate more clearly what happens to the economy when energy shocks occur. The study will also allow an examination of the efficacy of several policy options, including aggregate demand policies such as monetary and fiscal policy, changes in the taxation of other nonenergy factors such as labor and capital and energy policies for reducing the consumption of imported oil during an emergency. The latter includes not only disruption taxes on oil during an emergency but also such measures as oil stockpiles and price and allocation controls on petroleum.

Although the EMF has initiated seven studies, many important issues remain to be addressed. At its annual meeting in January the EMF senior advisory panel reviewed a dozen proposed topics for the next EMF study. Although the energy shocks topic was given first priority, energy and income distribution was a close second and international energy trade issues and constraints on energy development attracted considerable support. These topics were among several[9] identified for possible future development using the EMF approach.

[9] See [4] for a complete description of the topics that were considered.

ACKNOWLEDGEMENTS

The authors thank the 200 or so individuals who have participated in the six EMF studies completed thus far and especially George Dantzig, Martin Greenberger, William Hogan, Alan Manne, John Stanley-Miller, Stephen Peck, Richard Richels, Henry Rowen and Tom Woods for all the ideas presented here. The usual disclaimers apply.

The Electric Power Research Institute and the Department of Energy sponsor the Energy Modeling Forum. The Gas Research Institute has provided additional funding for EMF 5, EMF 6 and EMF 7.

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