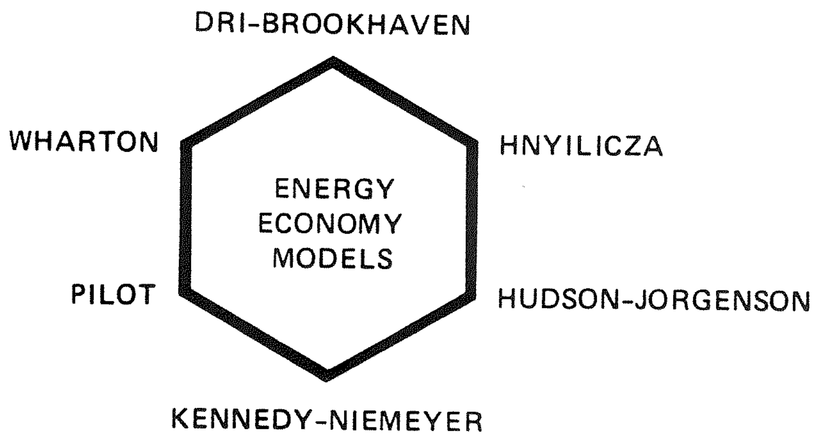
emf energy modeling forum

EMF REPORT 1
Volume 1
September 1977

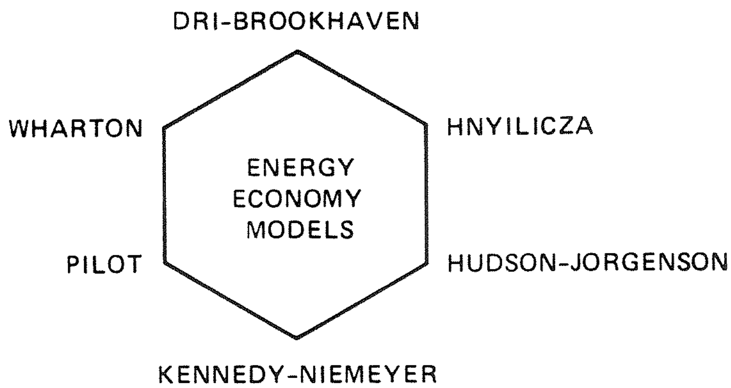
Energy and the Economy

Volume 1



ENERGY MODELING FORUM

ENERGY AND THE ECONOMY



EMF Report 1

Volume 1

September 1977

Energy Modeling Forum
Institute for Energy Studies
Stanford University
Stanford, California 94305

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EXECUTIVE SUMMARY

ENERGY AND THE ECONOMY

The Electric Power Research Institute created the Energy Modeling Forum (EMF) to improve the usefulness of energy models. Administered by the Stanford Institute for Energy Studies, the EMF operates through working groups of energy model developers and users conducting comparative tests of a variety of available energy models. To date, the EMF has completed one investigation--of the effects of changes in the energy sector on the domestic economy. Topics for future studies have been recommended by the EMF Senior Advisory Panel and further studies are in progress.

The first EMF working group, examining the link between energy and the economy, concentrated on the use of several large macroeconomic models as described in this report. Each model was represented in the working group by a technical team or expert. To compare the results obtained by these models, the working group developed a common set of assumptions and scenarios for analysis. Forecasts of absolute levels of output and energy consumption are not the focus of this study. Rather, the models are compared to uncover the differences or similarities in the estimates of the economic effects of changes in the energy sector, i.e., changes in relative energy prices or relative energy utilization.

The major conclusions derived from the models' output include:

- In the presence of constant energy prices, increases in economic activity produce similar increases in energy demands, although these may be moderated by trends toward less energy intensive products and services.

- Higher energy prices or reduced energy utilization need not produce proportional reductions in aggregate economic output. There is a potential for substituting capital and labor for energy and the contribution of energy to the economy, relative to these factors, is small.

- The models do show some substantial reductions in economic output resulting from higher energy prices. The magnitudes of these reductions are very sensitive to the substitution assumptions implicit in the models. Further, the impacts may be large for individual sectors of the economy.

- The benefits of energy substitution may be lost in part if energy scarcity impedes capital formation. Reduced energy inputs may cause lower levels of investment and, consequently, reduce potential GNP. This indirect impact may be the most important effect of energy scarcity.

In addition to the direct results of the models, the working group identified other conclusions concerning the strengths and weaknesses of the models and the methods they employ. The models are useful, each with different attractive features. The study of the impact of energy on individual economic sectors requires the use of the detailed models. The analytical processes applied by the EMF working group may assist in the use of these models. The development of simple approximations explains a model's structure and clarifies the important underlying assumptions. Despite their usefulness, however, the models simplify or exclude important characteristics of the link between energy and the economy. For example:

- All the models examined focus on the long run potential of the economy. Abrupt changes in energy availability or other policies with short term implications may affect the realization of this potential GNP, but are not within the scope of the models studied here.

- The models require assumptions about future population or labor force growth and the rate of technological change which, other things equal, determine the growth path of the GNP. The analysis in this study is directed at the changes in growth due to changes in the relative scarcity of energy, not to absolute levels of future economic activity. There may be some effect of energy price or availability on the variables whose values are here assumed. Any such effects would not be captured in the models.

- The representation of nonmarket behavior is difficult to include in the models. The effects of regulation, industrial organization, or the expectations created by government's future role are not well understood.

- The models treat environmental considerations in a rudimentary way. They do not address the causes and effects of persistent unemployment nor the impacts of unexpected embargoes. Financial sectors are highly stylized or absent in many of the models. Such important issues require different analytical approaches or major model extensions.

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ACKNOWLEDGMENTS

The composition of the working group was intended to be heterogeneous, and the contributions of the members display a similar variety. The modeling teams gave much of their own energy to the implementation of the frequently modified set of comparative scenarios. Other members contributed to the analysis of results or the preparation of the report in its several sections. Where possible, as in some of the appendices, individual authors are identified and individual responsibility is accepted. However, the main section of the report, Volume 1, represents the combined efforts of too many members of the working group to properly identify individual authors. While the working group is in general agreement on this report, not every member necessarily agrees with every statement. The responsibility for any remaining errors rests with the working group chairman. I thank all the members of the working group for their help and patience.

I offer particular thanks to Shailendra Parikh of Stanford for his tireless efforts. I express my special appreciation to Larida Stacy who, with the assistance of Joanne Eiseman and Donald Long, was responsible for the typing of many drafts of these reports and the complicated management of our paper flow. In addition, I thank Dennis Fromholzer who provided the computer support, Dorothy Sheffield for her editorial assistance, and John Riddell for his help at our first meeting.

I also thank the Electric Power Research Institute (EPRI) for its financial and moral support and the Stanford Institute for Energy Studies for its continuing assistance. Finally, I want to express my gratitude to Martin Greenberger who as the EPRI program manager has displayed an extraordinary interest in this project and made a significant personal contribution to its success.

William W. Hogan
Working Group Chairman
EMF Executive Director
Stanford University
September 1977

ENERGY MODELING FORUM

SENIOR ADVISORY PANEL

The Energy Modeling Forum seeks to improve the usefulness of energy models by conducting comparative tests of models in the study of key energy issues. The success of the Forum depends upon the selection of important study topics, the broad involvement of policy makers, and the persistent attention to the goal of improved communication. The EMF is assisted in these matters by a Senior Advisory Panel that recommends topics for investigation, critiques the studies, guides the operations of the project, and helps communicate the results to the energy policy making community. The role of the Panel is strictly advisory. The Panel is not responsible for the results of individual EMF working group studies.

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Dr. Harvey Brooks	Professor, Harvard University
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ENERGY AND THE ECONOMY
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ENERGY AND THE ECONOMY

INTRODUCTION

Energy use and the economy have grown together.

During recent decades, the national economy has produced a substantial rise in output. Energy consumption has experienced a similar increase. Between 1950 and 1973, the economy grew at 3.6% per year while energy consumption grew at 3.4% per year. It is natural to attribute a causal relationship to these patterns. Expansion of the economy raises energy consumption, and a plentiful energy supply is seen as a spur to economic growth. The common expectation, however, is that future energy supplies will be limited and expensive. This new perception of the energy situation has created a call for national action. If abundant energy is essential for future economic well being, a large effort is required now to guarantee that our needs are proper and are properly met.

But does economic growth depend on energy availability?

At the root of this national concern is the assessment of the dependence of the economy on energy. This is a complex problem. Energy availability affects every facet of our economy and energy is used in many different forms. What may be true for the use of electric power in aluminum production need not be true for the use of oil in home heating. Regional differences, the long lead times for major changes in facilities, and the uncertainties of the security of supply contribute to the difficulty of describing the interface between the energy sector and the remainder of the economy. It is not surprising, therefore, that there is a diversity of opinion about the nature and importance of energy-economic interactions. There is some evidence that the relationship between energy and economic growth is not immutable, but the degree of potential flexibility is disputed.

Are forecasts and other energy studies valid that do not include the possibility of such dependence?

The ramifications of large interactions are wider than it may seem at first glance. Energy forecasts are based customarily on projections of the future output of the economy. Suppose that this output is altered by the feedback effect from changes in the supply and price of energy. Then the energy forecasts themselves may be inconsistent. Thus, the magnitude of the energy-economic feedback bears on the validity of analytical studies that isolate the energy sector from the remainder of the economy. Such isolation affords an enormous simplification of analysis and is engaged in to some extent by most energy studies.[1]

The Forum is comparing runs of a variety of energy models to explore these questions.

It follows that analysis of the energy-economic interactions must precede evaluation of energy options. The purpose of this report is to summarize the Energy Modeling Forum's study of selected models of energy and the economy. These models come equipped with an ample set of limitations, and their use is qualified by the usual caveats. Some of these are discussed in the report or the appendices. The reader will recognize the narrow scope of this analysis in examining GNP and prices as the representatives of economic activity to the exclusion of environmental issues, problems of income distribution, changes in international trade, or a host of related subjects. In part this is caused by the intent to compare results across models and the need to limit the scope of the study. The detailed models have rich structures, and many can be applied to a wider spectrum of issues than is considered here. However, the limited questions addressed in this study are important and the model comparison illuminates several valuable conclusions. Early on, the analysis rejects the straw man of a lockstep linkage between energy and the economy. Reductions in energy utilization need not produce proportional reductions in economic activity. The small value share of energy in the total economy is shown to be an important but incomplete component of this story. It is the potential for substitution that dominates this analysis and establishes the

The value of energy input is small compared to the total economy.

importance of large changes in energy availability in determining the resulting changes in economic activity. The final theme centers on the indirect effects of energy on capital, which may compromise some of the benefits of substitution.

The paper begins with the history of the Energy Modeling Forum. After describing the role of energy models, the paper develops some fundamental concepts that help explain the structure of the models used in this study. The paper concludes with a comparison of model results and their implications for the evaluation of the energy-economic interactions. Details of the analysis and relevant supporting material are left to a series of appendices.

THE ENERGY MODELING FORUM

The expanding number of energy models provides a framework for analysis and debate.

Behind sharp disagreements on energy questions, there are often simple but fundamental differences in views about the nature of the problem. If made explicit, these alternate views can be compared and evaluated. Formal models implemented on computers provide a capability for organizing and extending the debate about the impacts of future energy alternatives. In many settings, energy models are integrated into the specification and evaluation of energy options, but their full potential is not being realized. The sudden increase in energy policy concern has produced an expansion of energy model development effort, but these new capabilities are not widely understood and are not applied to many relevant energy problems.

But these models must be better understood through the improved communication the Forum provides.

If energy models are to contribute to the improvement of the energy policy debate, there must develop a wider appreciation of current model capabilities and a better specification of model limitations needing new research. This presumes regular communication between the developers of energy models and potential users. To meet this need, the Electric Power Research Institute is sponsoring the Energy Modeling

Forum, a project administered through the Stanford Institute for Energy Studies. The purpose of the Energy Modeling Forum (EMF) is to promote communication between model users and developers through the comparative application of current energy models to the analysis of priority energy issues. Disciplined by the focus on a specific question of importance, the EMF operates as a combined group of energy model developers and model users. By structuring comparative tests, the EMF seeks to clarify the central implications of the models and the assumptions on which these results are based. In the process, common perceptions of energy problems emerge, new priorities for analysis are identified, and the uses of the models are illustrated.

The Forum's pilot study concerns the relationship between energy and the economy.

The first EMF working group was organized to develop operating principles and demonstrate the viability of the basic concept. For its initial study, the group examined the link between the energy sector and the economy. What is the nature of the link between the energy sector and the remainder of the economy? How strong are the feedbacks? Will changes in energy utilization have a significant effect on the future of the economy?

Can the use of energy be diminished without affecting output?

The relationship between the energy sector and the economy is central to the evaluation of energy options. Most concern with energy issues arises from the assumption that the character of future energy availability will have a major impact on the quality of life, and the level of economic activity is a primary measure of this quality. Opinion is divided sharply on the structure of the link between energy and the economy. Basic physical laws indicate that some energy is required for every activity and if adequate energy is not available the activity cannot take place. From this perspective, the historical growth of energy and the economy is cited as evidence that their future growth cannot be separated. In the short run, most would agree, for we must use the equipment and processes now in place, and their range of energy utilization is narrowly restricted. In the longer run, however, new equipment can be purchased, alternate transportation systems designed, the mix of desirable products changed, and new technology introduced. The same level of output might be obtained with a lower level of energy utilization and the quality of life maintained or even improved, some would say. This perspective is supported by the evidence of different energy utilization patterns and higher energy prices in other industrial nations. The history of low energy prices may explain the growth of energy demand in the United States.

The answer is central to future policy choices.

If growth in energy availability is essential to the growth of the economy, then large expenditures are indicated for programs directed at expanding long run energy supply and lowering energy costs. However, if substantial flexibility exists for adjusting energy utilization and economic output, then programs which facilitate this adjustment may be employed. The best policy probably requires a careful blending of both approaches, but it is certain that these choices will be influenced heavily by the expectations of the impacts on future economic growth. It is essential to understand the links between energy and the economy.

THE ROLE OF MODELS

Computer modeling allows pieces of a problem to be analyzed separately, then combined.

Energy models alone cannot dispose of these difficult issues. They augment our capabilities for organizing the collective understanding of a problem. Modeling does not replace careful thinking, but seeks to exploit it. A model records what we know by providing an accounting framework, organizing the data and key relationships. At the heart of most models is some simple classification scheme. For example, the model may describe all energy consumption in terms of a few sectors, aggregating the millions of households, commercial establishments, or industries. This permits the separate but consistent analysis of the major problem components. Specifying how these components connect may simplify other complex interactions.

Hence, one analysis may characterize the effect of regulation on the supply of natural gas. A separate analysis of substitution relates the supply of natural gas to the industrial demand for oil. When combined, the two analyses are a model of the relationship between regulation and the industrial demand for oil. In the process of specifying each analysis and the interface, the important assumptions are illuminated and made easier to validate. Is it true that oil and gas are perfect substitutes in all industries? If not, how sensitive is this assumption in the estimation of the effect of regulation on the industrial demand for oil? If the model is explicit, these questions can be addressed systematically. The implications of a given hypothesis about the structure of the energy system can be pursued. If the model also is detailed, computer implementation may be a further aid in pursuing the needed calculation. These contributions of modeling are substantial. The accumulation of knowledge and the pursuit of the implications of that knowledge are the essence of sound analysis. Formal modeling makes the process explicit and promotes its orderly evolution.

But models are at best only simplified approximations of reality.

The limitations of models are important to recognize. The basic limits of our understanding are transferred to a model. Hence, the effects of noncompetitive practices are not to be found in the study of models assuming perfect competition. A model does not create a new theory, it explores the existing theory, often in a highly simplifed fashion. This simplification is essential in modeling, permitting quick analysis of many relationships and the clarification of basic causal mechanisms. Without simplification, the only model of reality is reality itself, and only one experiment is permitted. With a model, many experiments are possible. And, unlike reality, we can take them or leave them. But the model is only an approximation to reality and must be judged accordingly. Many approximations to the same reality are possible. The application of any one model must be guided by the context of the questions addressed. For problems as complex as the evaluation of energy futures, there is no single model which addresses all issues. There are many problems for which there are no models at all. Energy models do not replace the effort of the analyst in determining the appropriate assumptions and problem structure, but they do extend the scope of the problems that can be studied.

We start with a simple model. It can be extended as its deficiencies become clear.

The benefits of simplification and the potential for detail are found in the range of available models of energy-economic interactions. Very simple aggregate analyses of the interaction can place the problem in perspective. These aggregate models provide the conceptual background for the evolution of more sophisticated systems. As the potential deficiencies of the simple models are identified and the assumptions relaxed, more detailed models develop and the range of application expands. Therefore, before presenting the results of the sophisticated models participating in the EMF study, a basic framework is developed for characterizing the key concepts underlying the interaction between the energy sector and the economy.

A BEGINNING FRAMEWORK FOR ANALYZING ENERGY AND THE ECONOMY

The issue here is the impact of a relative scarcity of energy. None of the models implies that energy is not needed for the economy. If energy prices remain stable, then an increase in economic activity should produce an increase in the demand for energy. Of course, the future growth of energy demand may be less than the historical growth because of lower projections for population increase or a trend toward a disproportionately higher growth of the less energy intensive sectors of the economy. The difficult question is, can energy demand growth be dampened further by higher energy prices without proportional reductions in economic activity?

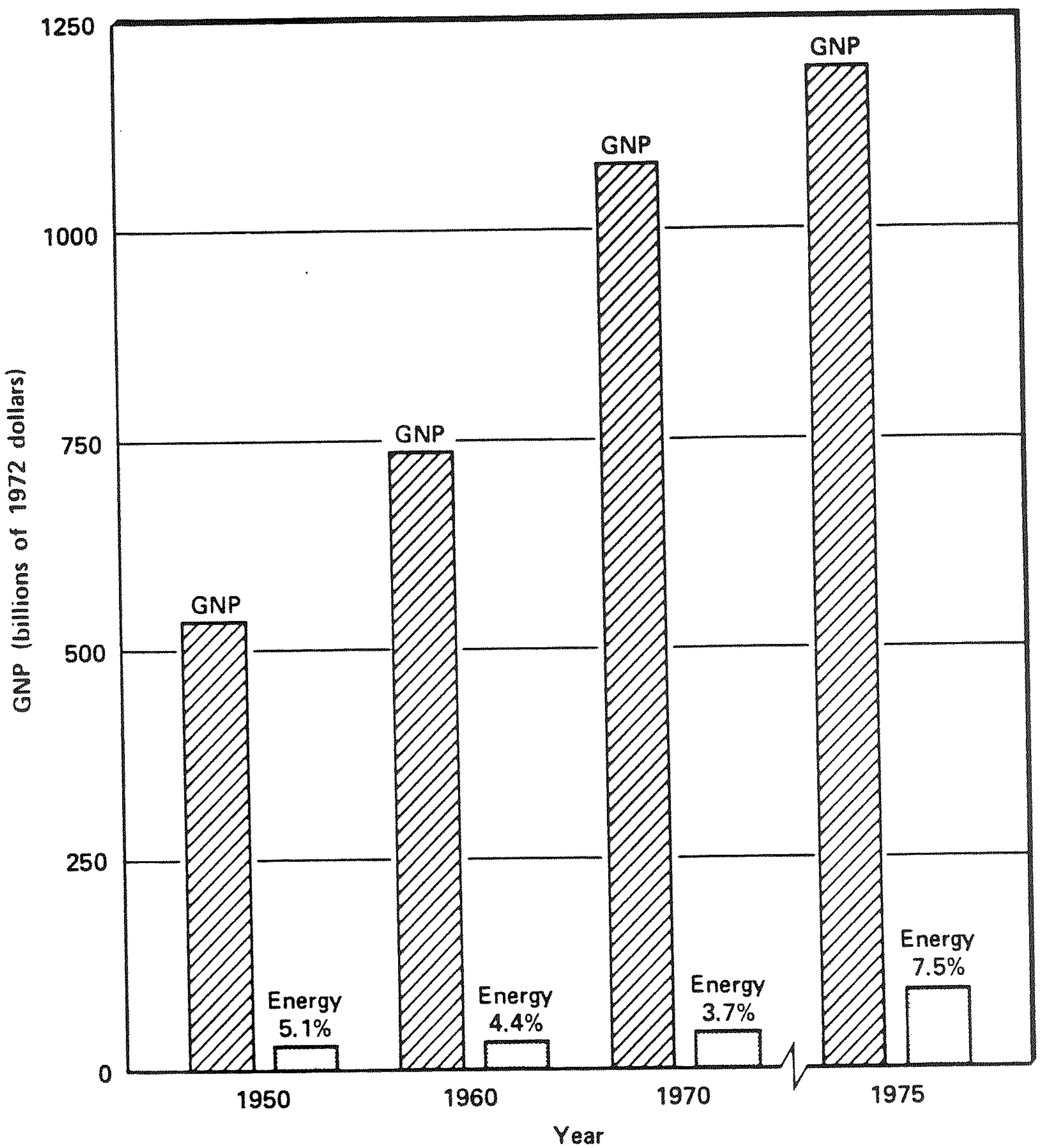
The value of energy input is small compared to the total enconomy.

For simplicity, we restrict attention to the long run, when energy equipment and processes can be changed substantially. In the short run, the character of the problem is different and different models are appropriate. As a further simplification for this beginning discussion, we represent the economy in terms of just two inputs--energy and all other items. Note in Figure 1 that energy is only a small component of the total U.S. economy. As of 1970, the value of primary energy inputs did not exceed 4% of the GNP. The analogy of an elephant-rabbit stew illustrates the implications of this low value share. If the recipe for such a stew calls for just one rabbit (the energy sector) and one elephant (the rest of the economy), won't it still taste very much like elephant stew?

Hence, changes in energy choices need not dominate future economic activity.

If energy prices had not risen after 1970, it is likely that energy demands would have grown at about the same rate as the GNP. The 4% ratio would then continue into the future. But what is the effect when energy costs double and there is sufficient time for the economy to adapt? One estimate of the impact may be obtained by assuming a constant recipe. Suppose the rabbit is paid for with part of the stew. Then an additional 4% of the stew (GNP) must be allocated to cover the doubling in the cost of the rabbit (energy). In fact, other recipes are available that call for less rabbit and, therefore, lead to lower costs. Under these assumptions, the first doubling of energy costs would produce, at most, a 4% loss in GNP.

With a more complicated argument, it can be shown that a small decrease in energy supply leads to a decrease in economic output proportional to the value share of energy in the economy. At a 4% value share, a 1% reduction in energy input would produce a 0.04% drop in total output. By this argument, a small percentage change in energy availability produces a considerably smaller percentage impact upon the economy as a whole.[2]



SOURCE: See Note 3.

Figure 1 GNP and Energy

The degree of potential substitution determines the importance of energy.

This simple analysis provides some insight but it suffers from a major defect in failing to represent accurately the flexibility of energy utilization in the economy. The processes for future production and utilization of energy are not fixed immutably. Insulation, efficiency improvements, and changes in the mix of input factors can alter the energy requirements for a fixed level of output. Such substitution possibilities can modify the economic impact of changes in the energy system. Flexibility in energy utilization is a central factor in determining energy-economic feedback, and its treatment varies widely among the many different energy models.

THE ROLE OF SUBSTITUTION

The aggregate measure of substitution is similar to the elasticity of demand.

The specific processes for energy substitution may be varied and intricate. Therefore, even if it is generally agreed that some substitution is feasible, it may not always be possible to identify the specific technological options available. The morass of detail may be approached gradually by expanding our first simple model and the beginning arguments based on the value share of energy. We explicitly assume now that substitution is possible between energy and nonenergy inputs to the economy. For the purpose of the present discussion, this flexibility can be summarized in economists' terms as the elasticity of substitution. Ignoring the feedback to the economy or other inputs, this parameter is the same as the elasticity of energy demand. It measures the proportional response of energy demand to a change in energy prices. Hence, if the elasticity of demand is -0.3, a 10% increase in energy prices produces a 3% decrease in energy demand.

The elasticity of substitution is the index of aggregate model behavior.

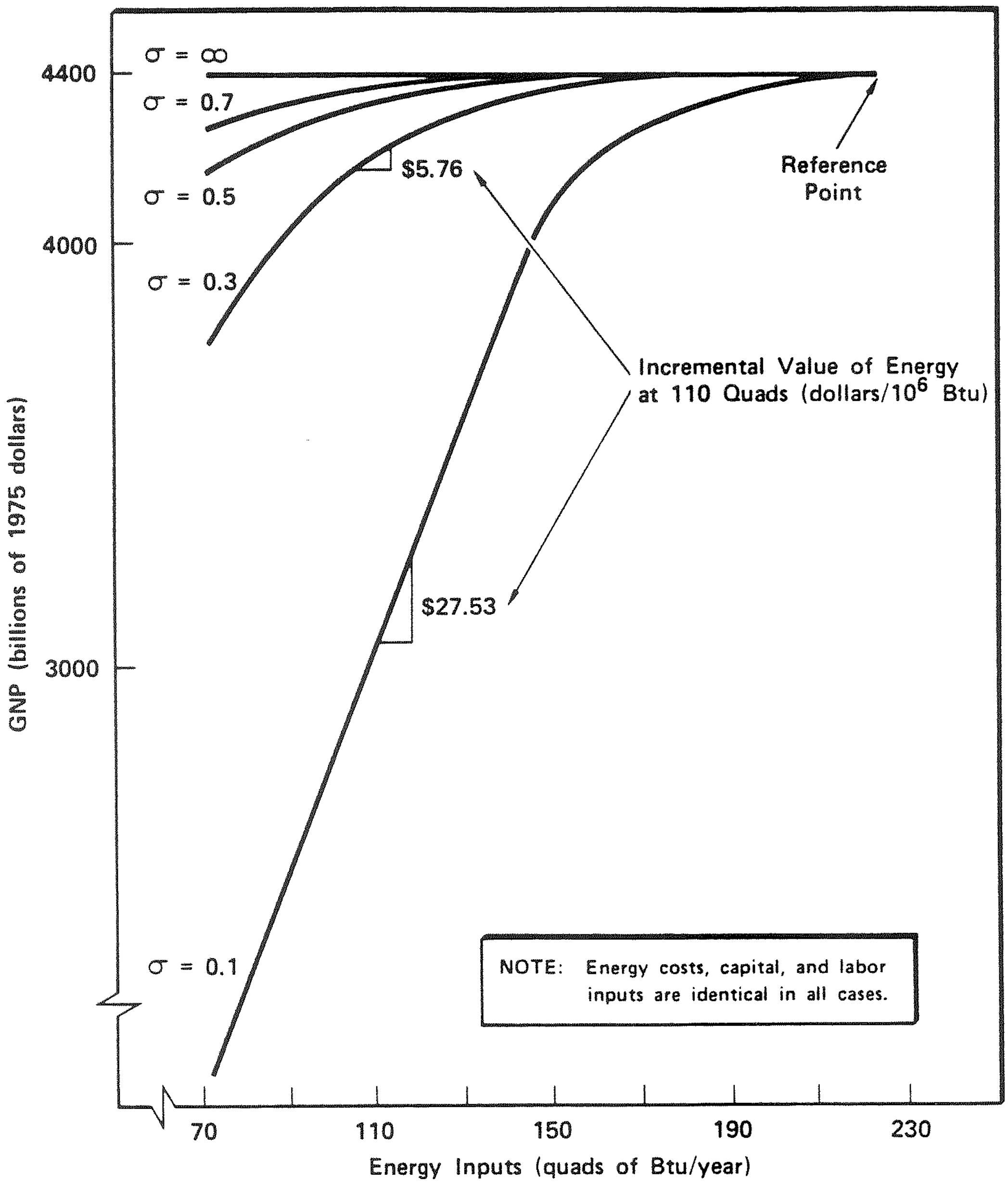
This concept, the elasticity of substitution, provides a convenient index for summarizing the aggregate behavior of the detailed models. If we assume that inputs of other factors such as capital and labor are held constant, then the elasticity of substitution virtually determines the feedback effect of the energy sector on the rest of the economy. The implications of alternate elasticity estimates are shown in Figure 2. This depicts the GNP in the year 2010 as a function of energy input, holding other inputs constant. It is assumed that a Btu tax is imposed gradually to reduce energy consumption. Such a tax might be levied, for example, to mitigate environmental impacts or lessen import vulnerability.[2]

The analysis is based on a hypothetical reference forecast, but the qualitative conclusions are not sensitive to this reference. A small change in energy availability has almost no effect on GNP. The loss in output is exactly balanced by the savings from the reduced expense of energy. This is what the price represents, the value of the product at the margin. This value will change as the quantity of energy input changes but the output does not decrease in proportion to the decrease in energy input. Substitution of other input factors compensates for the reduction in energy input.

Seemingly small changes in the elasticity of substitution produce major changes in economic impact.

The importance of the long run elasticity of substitution is startling in the context of this analysis. 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. Seemingly small changes in the substitution potential produce major changes in economic impact. Even the smaller GNP reductions have a large value, however. If the economy is growing at 3% in real terms and we discount future consumption at 6%, a 1% reduction in annual GNP corresponds to a present value of nearly half a trillion dollars. This is only 1% of the present value of future output, but it would justify a substantial research investment aimed at developing low cost technologies which can expand energy supply or improve the efficiency of energy utilization.

An alternative indicator of the economic impact of energy scarcity is found in the implicit tax associated with a given energy reduction. As a measure of the marginal value



SOURCE: See Note 2.

Figure 2 Economic Impacts of Energy Reductions in the Year 2010 for Various Elasticities of Substitution (σ)

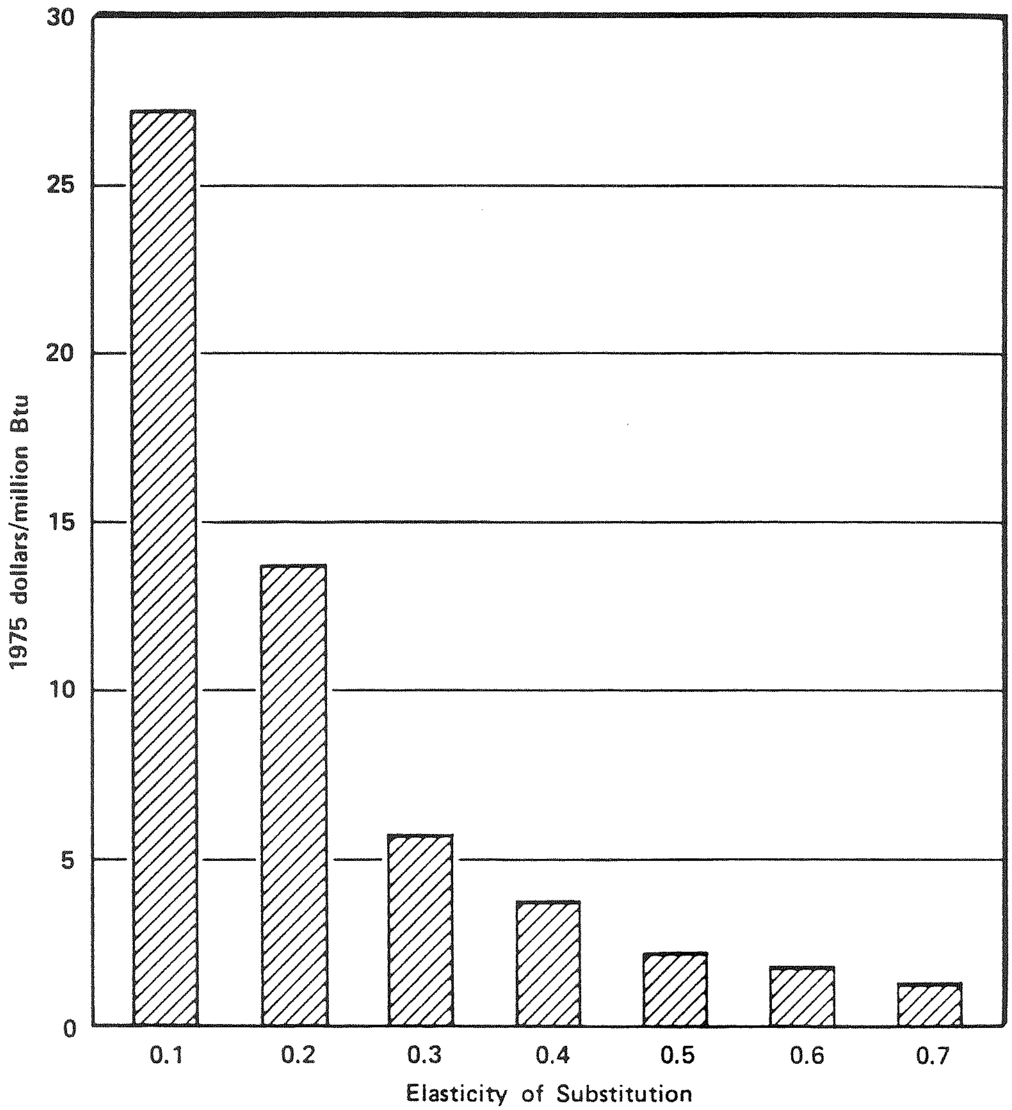
of energy, this tax may be a more appropriate barometer of the importance of energy scarcity. Although the specific tax is determined by the arbitrary assumptions of the reference forecast, the sensitivity to changes in the elasticity of substitution repeats the results of the analysis of GNP. The implicit tax for the 50% energy reduction from the reference forecast is shown in Figure 3. If the elasticity of substitution is as low as 0.1, the necessary tax is $27.53/million Btu, a tax of over 3400%. But if the elasticity of substitution is as high as 0.7, the tax is reduced to $1.26/million Btu or 158%.

Available estimates of the elasticity of substitution suggest some flexibility in the economy.

What is the proper elasticity of substitution? The estimation of this parameter has been the subject of many studies but there is no definitive resolution of the issue.[4] There are difficulties in comparing definitions, problematical data, and disputes about the relevance of past experience in extrapolations to the future. A consistent interpretation of these studies indicates the elasticity of substitution is between 0.2 and 0.6, although there is evidence for higher and lower values. As we see below, the detailed models which have an explicit representation of the full economy yield values between 0.3 and 0.5 for the elasticity as defined here, in terms of primary energy prices. This indicates that there is substantial but not unlimited flexibility in energy utilization in these models.

The benefits of substitution may be lost in part if investment is curtailed.

The estimates in Figure 2 of the impact of energy reductions are based on a simplified, partial analysis of the economy. This shows the potential of substitution between economic inputs to absorb energy input reductions with less than proportionate reductions in economic activity. However, changes in energy input have a further dimension of feedback to the economy. This additional dimension centers on the pattern of capital investment over time. Reductions in energy input lead to changes in the rate of return on capital as well as reductions in the level of total output. Investment, savings, and capital use are altered as a consequence. Over time, these



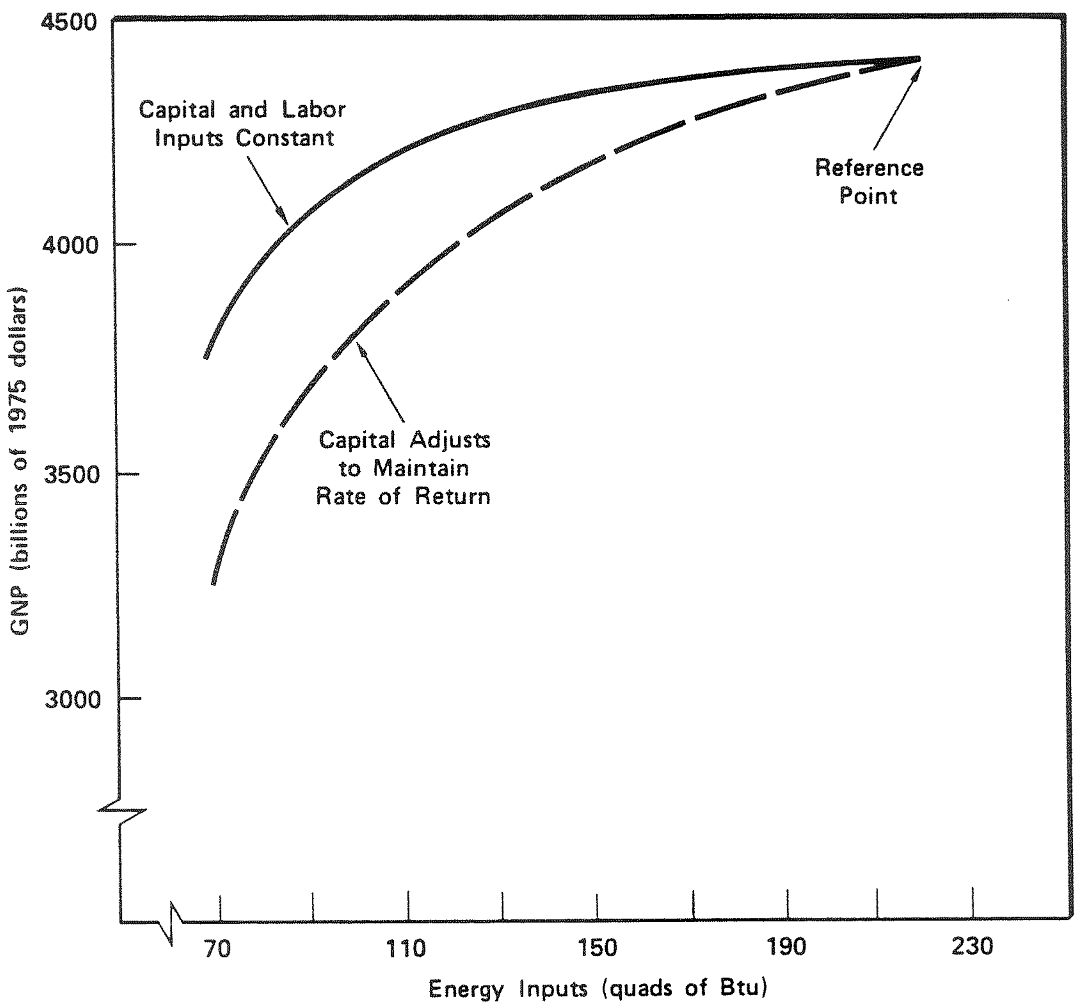
SOURCE: See Note 2.

Figure 3 Implicit Tax, Cutting Energy Use in Half by 2010 effects may cumulate into significant changes in the capital stock and, therefore, in the productive capacity of the economy. It is difficult to analyze these complex interactions; in fact the sophisticated models participating in this EMF study are required for this task. As an approximation, however, we can extend the partial analysis to illustrate the magnitude of the economic effects of changes in capital input. For this purpose, expand the beginning framework to include three economic inputs--energy, capital, and labor. Now, instead of holding capital and labor constant as energy input changes, let capital adjust to maintain a constant rate of return. The impact of this new assumption, for the case of an elasticity of substitution of 0.3, is displayed in Figure 4. For a 50% reduction in energy input, there is a 4% reduction in GNP when capital is held constant, but the reduction is 11% of GNP when energy is reduced and capital changes to maintain a constant rate of return. In this case, the capital change effect exceeds the direct effect of the energy reduction.[5] Thus both substitution and capital adjustment processes are important in considering the feedback effects of energy on the economy. When both these processes are taken into account the conclusion remains that while energy reductions do have a substantial economic impact, the GNP reduction is proportionally smaller than the reduction in energy output.

THE REAL MODELS

More detailed models can improve the representation of the substitution potential.

Several immediate difficulties can be found in the aggregate analysis of the preceding section. First, the aggregation itself may disguise distinctly different behavior in component economic sectors. This behavior is of interest in itself and can be captured only by more detailed models. Second, the aggregate substitution parameter does not provide a description of the new processes and technologies that must be adopted. Again, more disaggregated analysis is necessary to provide the detail to support the credibility of the simple analysis. Third, investment, savings, and capital accumulation might be affected by the price and availability of energy. Here is another reason for the construction of more sophisticated models.



SOURCE: See Note 2.

Figure 4 Economic Impact of Energy Scarcity in the Year 2010 for Alternate Capital Assumptions (Elasticity of Substitution $\sigma = 0.3$)

The detail in the participating models covers a wide range.

Increased detail is characteristic of most of the analytical extensions in the models included in the EMF analysis.[6] The most aggregate of these models, developed by Hnyilicza of MIT, organizes production around the inputs of four factors to produce energy and nonenergy outputs. Markets balance supply and demand in each period as the system evolves over time. The parameters of this model have been empirically estimated. It provides, therefore, a first estimate of the potential flexibility of energy utilization. This also serves as a reference for comparing the results of more disaggregate models.

At the next level of detail, found in the models of Hudson-Jorgenson and Kennedy-Niemeyer, the economy is divided into nine sectors with special attention focused on a variety of energy products. A richer array of production and utilization arrangements becomes possible in these models. When aggregated to the level of the beginning analysis, these models may provide a means for representing variable elasticities of substitution.

This detail is pursued further in the PILOT model of Stanford, the Wharton model, and the DRI-Brookhaven system. The range is from the 23 sector economy in PILOT to the 100 sector economy in the DRI-Brookhaven model.

Each of these models is too complex to comprehend in its entirety except by analysis of individual components and the rules for combining these components. This complexity is a cost of credibly representing the flexibility of energy utilization. Computer implementation permits rapid calculation and examination of the models' implications. And the results can be aggregated to the level of the simpler framework. For example, the elasticity of substitution is shown in the simpler framework to be an important summary measure in determining the economic impact of energy system changes. This insight can be applied to the comparison of the detailed models if we identify them in terms of their substitution assumptions.

The models extend from assumptions of little flexibility to substantial substitution possibilities.

When viewed from the perspective of energy substitution assumptions, the participating models may be divided into two categories. Two models, the Kennedy-Niemeyer and PILOT systems, employ structures which implicitly assume little flexibility in energy utilization. Later we shall see that their results are consistent with the first discussion of a fixed recipe in the elephant-rabbit stew. The remaining models employ structures which can incorporate substitution between energy and other factors. In addition, the parameters for the major components of these models are estimated empirically and, when aggregated, provide alternate estimates of the elasticity of substitution. We shall see that their aggregate behavior is consistent with the results of the simple framework.

Six test scenarios were run.

Six test scenarios were designed for these models. These scenarios are not intended as forecasts. To achieve some consistency, the working group compromised individual judgments as to the most likely futures. The scenarios are designed, instead, to display the feedback links embedded in the models. The details of the scenarios are explained in an appendix.[7] They cover different economic growth assumptions and examine severe reductions in energy availability or increases in energy costs.

The models assume long run full employment.

The comparison of the model structures and the design of the test scenarios reveal important assumptions common to all the participating models. Because of their focus on long run considerations, the impacts of temporary unemployment are ignored in all but the Wharton model. The economy is assumed to move quickly to a predetermined full employment growth path. The models concentrate on the evaluation of potential GNP. Hence, the models are not suited to the evaluation of policies which may produce persistent unemployment, nor are they suited to the study of unanticipated energy supply interruptions. These are major areas of policy concern, but beyond the scope of the participating models.

Standardized population and productivity assumptions determine a common GNP growth pattern.

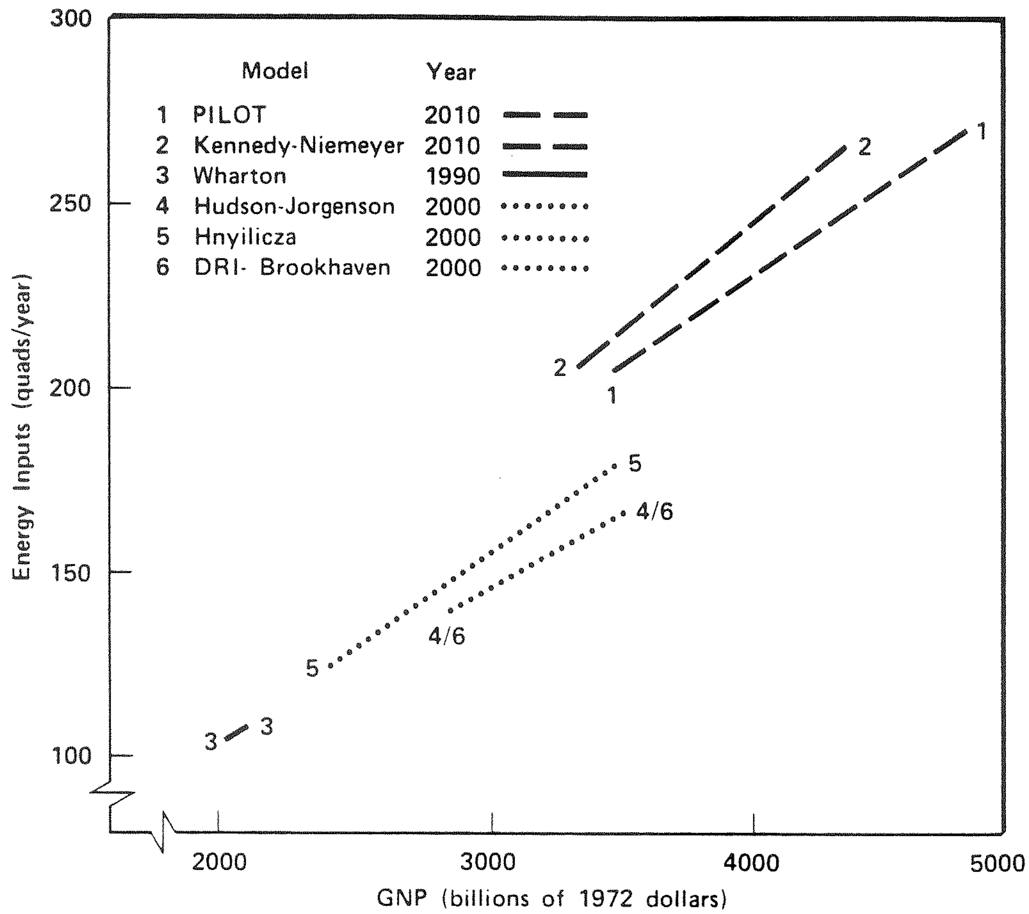
The importance of the full employment assumption is illustrated by the fact that all the models require as input the rates of population growth and productivity increase. The rate of population growth virtually determines the growth in the labor force. The rate of productivity increase describes the temporal improvement of technology which expands output for a given level of input factors. If the availability of other factors is not changing, then the growth in productivity plus the growth of employment must determine the growth of the GNP. In the presence of constant factor prices, therefore, the rate of GNP growth is an assumption in the models. A base case scenario standardizes the population and productivity inputs. All the models then produce the same growth path for GNP. The models are designed to examine the feedback from the energy sector to the economy, but they are not intended to provide a reference economic forecast.

THE MODEL COMPARISON

Four of the scenarios designed to test the models provide insight into the measure of the interdependence between energy and the economy. In addition to the base case, a high economic growth scenario is constructed by employing higher growth rates for population and productivity. These two alternate economic forecasts then are subjected to a collection of energy constraints designed to severely restrict energy supply, substantially increase energy prices, and produce curtailments of economic output.

With stable energy costs, increased economic activity produces increased energy demand.

The comparison between the base case and high growth case provides insight into the structure of the models. The role of flexibility in energy utilization and the impact of energy sector changes on the economy should not be confused with the direct effects of the economy on energy demand. Energy utilization may vary in the presence of changing energy costs. But when energy prices remain nearly stable, it is reasonable to expect economic growth to produce a growth in energy demand. A test of the models in this regard is contained in the comparison of the base case and the high growth case runs. The results confirm that all the models possess this expected property, some by assumption, others through parameters estimated empirically. Figure 5 compares the base and high growth cases in terms of energy input and economic activity for each of the models.



SOURCE: See Note 8.

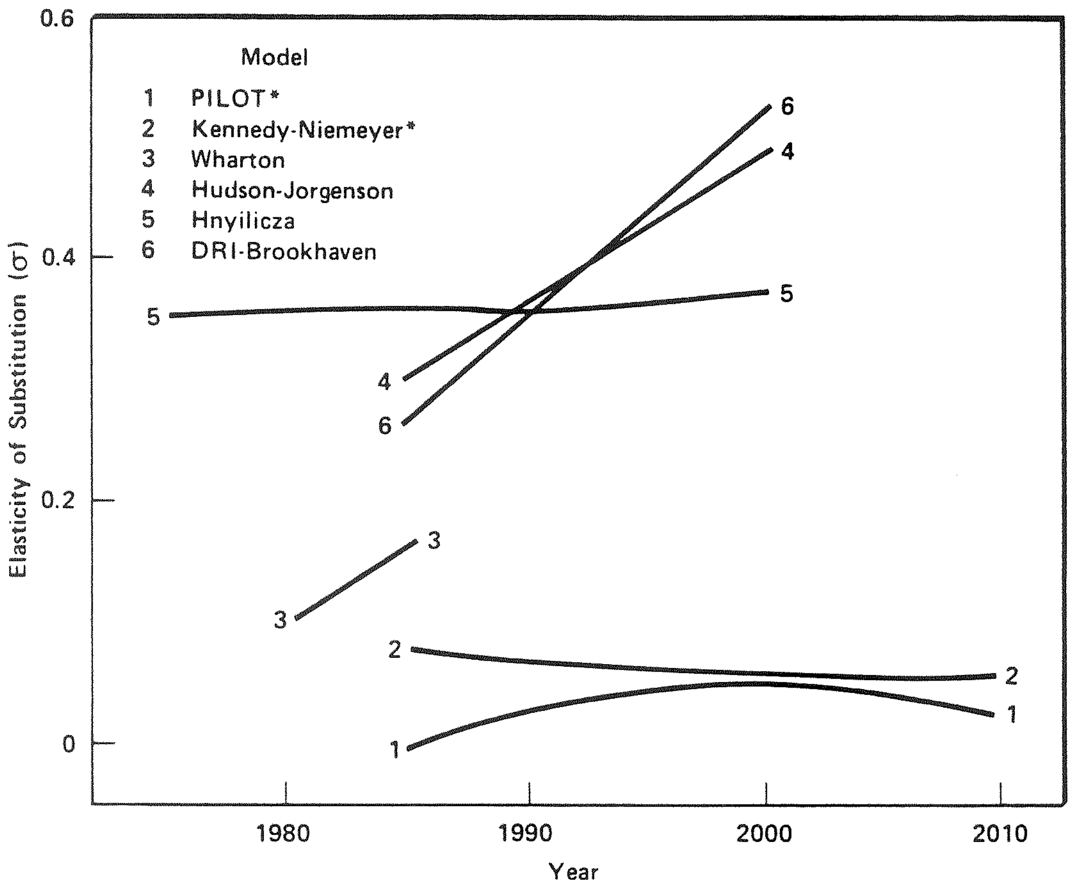
Figure 5 Energy Response to Economic Activity (Energy Requirements Given GNP in the Base and High Growth Cases)

Increasing energy costs may weaken the link between economic activity and energy demand.

When all other things are not held equal and energy constraints are imposed, both the utilization of energy and the growth of the economy may be affected. If the potential for energy substitution is low, the imposition of severe energy constraints should produce high energy prices and large reductions in output, maintaining a nearly constant ratio of energy input to economic output. If the potential for energy substitution is high, the energy constraints will have less effect on prices and output, and should produce a marked change in the energy-output ratio.

The base case and the high growth scenarios with and without energy constraints, or Btu taxes, provide tests of the feedback effect embedded in the various models. The estimates of the aggregate elasticity of substitution in each model are shown in Figure 6 for the base case. The implicit elasticities in the models need not be constant over time nor for different levels of price changes. In fact, the sophisticated models include many avenues for variation in the substitution potential. But the aggregate elasticity remains as a useful summary index of the models' behavior. These results confirm the earlier classification of the models into those which assume limited substitution and those which employ a structure designed to capture the potential substitution empirically. Both the Kennedy-Niemeyer and the PILOT models, which assume limited substitution, display aggregate elasticities below 0.1 and generally close to zero. The remaining models, which include detailed substitution possibilities, trend toward long run aggregate elasticities between 0.3 and 0.5. From the previous discussion, this range of substitution potential is seen to include substantial but not unlimited flexibility in energy use.

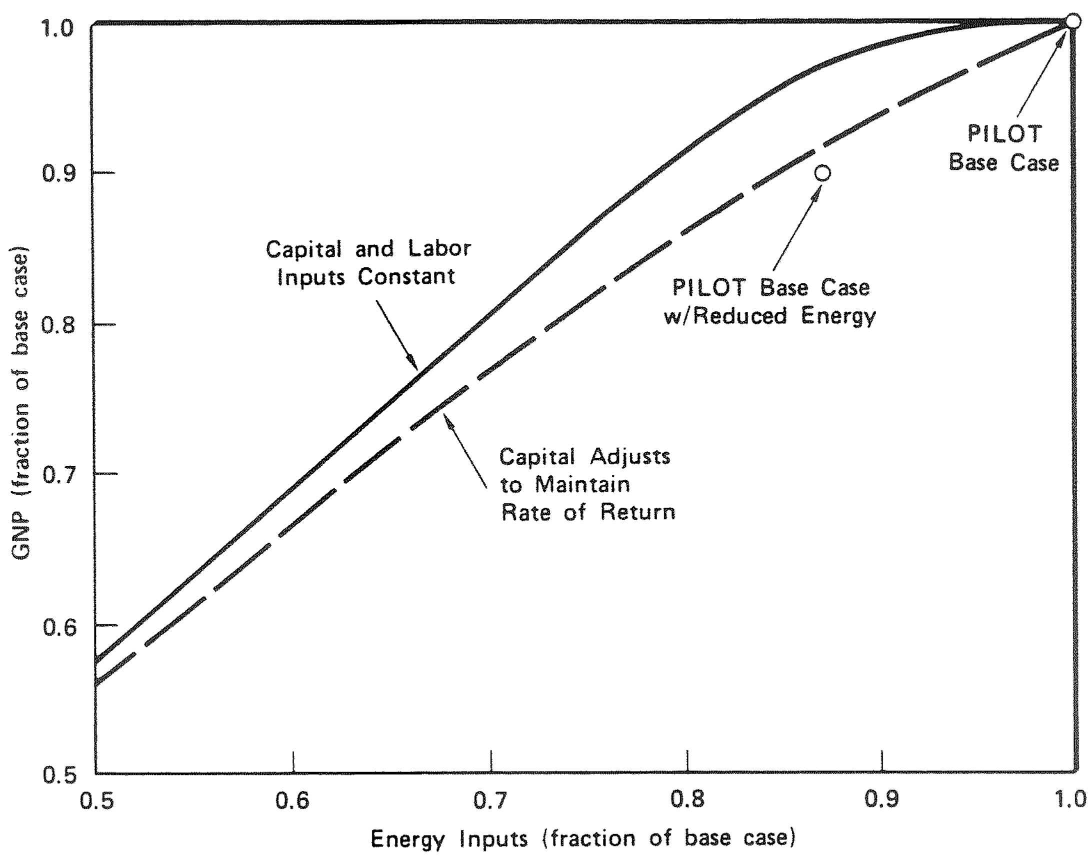
The value of the aggregate analysis in summarizing the results of the detailed models is illustrated in Figures 7 and 8 for models representative of each substitution assumption. Here, the actual results of the models are displayed for the base case and the base case with tax and compared to the prediction that would be obtained from the three factor model with energy, capital, and labor. In Figure 7 the results are



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

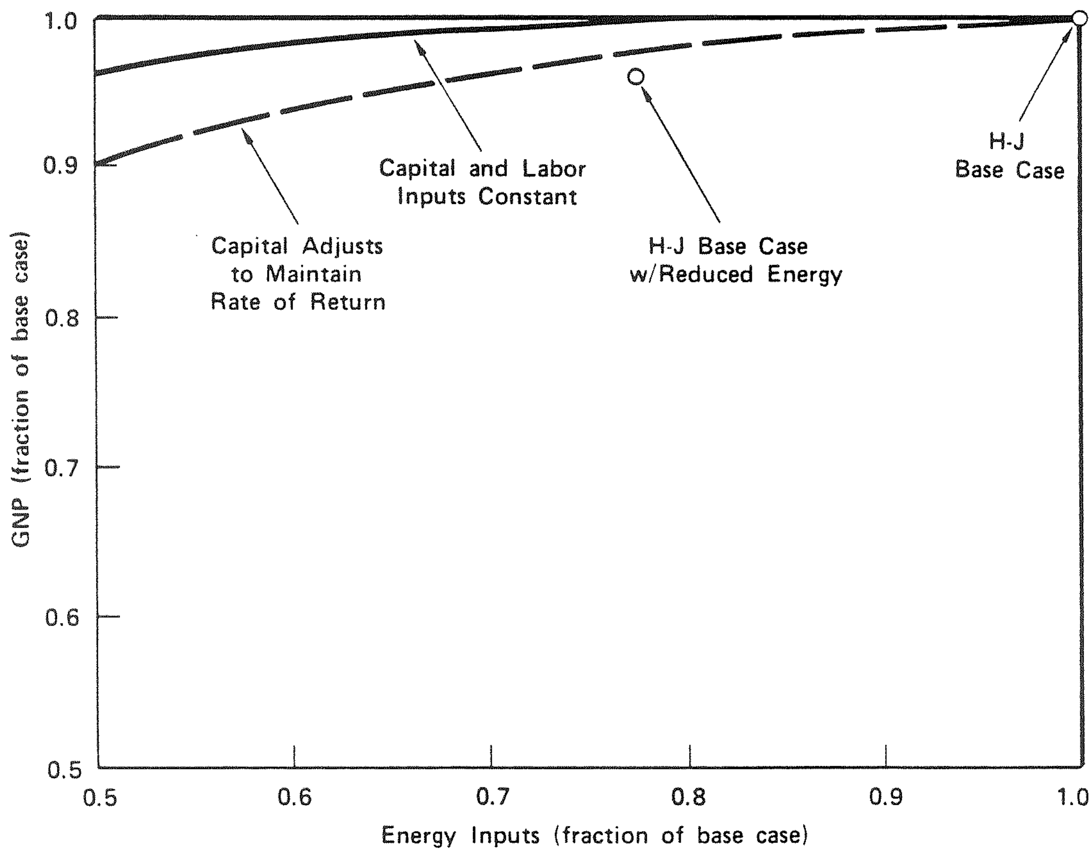
SOURCE: See Note 8.

Figure 6 Aggregate Elasticity of Substitution (Calculated Using the Outputs for the Base Case and the Base Case With Constraints)



SOURCE: See Note 8.

Figure 7 Comparison of PILOT Actual Results in the Year 2010 With the Simple Model of Substitution, Using PILOT's Implied Elasticity of Substitution (σ = 0.03)



SOURCE: See Note 8.

Figure 8 Comparison of Hudson-Jorgenson Actual Results in the Year 2000 With the Simple Model of Substitution, Using Hudson-Jorgenson's Implied Elasticity of Substitution ($\sigma = 0.49$)

shown for the PILOT model. Figure 8 depicts the same comparison for the Hudson-Jorgenson system. The simple analysis is not perfect, but it simulates the major portion of the aggregate effect found in the detailed models. It provides a guide for the proper use of the detailed systems by illustrating the central ideas embedded in the structure of the full models. The value share of the energy sector is a small component of the total economy. Small changes in energy input, therefore, have a small impact on aggregate output. For large changes in energy input, the estimate of the economic impact is significantly affected by the estimate of the elasticity of substitution.

The study has succeeded in identifying a central issue but has left many other issues unattended.

At this juncture it is useful to recall that our simple measure of economic impact, gross output, is not a complete description of all the effects of changing energy futures or the sole representation of the quality of life. Environmental effects play an important role in the evaluation of any energy option but, given our accounting system, they are excluded from direct consideration. Similarly, the international political implications of alternative energy conditions may be the dominant focus of concern. The economic impact may be overshadowed by national security priorities. Even within the realm of economic measures, important issues such as the distribution of income are submerged in the aggregate analysis. Evaluations of externalities or more detailed characterizations of the economy are essential in the assessment of specific energy options. Hence, the measurement of the aggregate elasticity of substitution does not complete the story. It is the essential first step. It is in the pursuit of complete analysis that the more detailed models establish their value. By exhibiting how individual industries respond to changing energy conditions, it becomes possible to estimate the environmental consequences of new energy options. By segregating demand by fuel type, the import and national security implications become more apparent. It is not the purpose here to examine the role of the detailed models in the study of these issues. Rather, the objective is to isolate the contribution of the models to the assessment of one important issue, the feedback from the energy sector to the economy. In exploiting the value of simplification, however, we should not neglect the contributions of the more detailed models. Where detail is crucial, a simple analysis does not suffice.

IMPLICATIONS OF THE MODEL COMPARISON

The economy has some flexibility but energy is important.

The implications of the comparison of models of the aggregate energy-economic interaction are significant. If there is no substitution, reductions in energy use produce corresponding reductions in economic activity. But if the higher estimates of the elasticity of energy demand are accepted, it follows that major changes in energy utilization can be achieved without corresponding changes in total economic activity. Even the recognition of the energy-capital effects embedded in the models does not alter this conclusion. However, we are not freed from difficult tradeoffs. The absolute impacts of the change in economic activity are significant. A given reduction in energy supplies may produce only a 1% reduction in GNP each year, but this can be a large loss in absolute value. It may justify a substantial research investment aimed at developing low cost technologies which can expand energy supply or improve the efficiency of energy utilization.

With some flexibility, energy sector models are still valid.

At a more technical level, the aggregate analysis can have important implications for energy modeling. If there is little energy substitution, the feedback effect is significant and energy models must account for this effect in representing the energy system. If the substitution potential is pronounced, the feedback effect is relatively small and separate energy sector models that hold aggregate economic activity constant can be justified. The changes in energy utilization and economic costs can be represented adequately by the first order effects contained in traditional demand curve analyses. This permits important modeling simplifications and expanded detail for the improved description of the operations within the energy system. Of course, the restriction to an energy sector model eliminates the capability of the full economy models to examine changes in the composition of economic activity.

NOTES

1 See, for example, the recent report of the Ford Foundation's Nuclear Energy Policy Study Group, Nuclear Power Issues and Choices, Ballinger Publishing Company, Cambridge, Mass., 1977.

2 Hogan, W. W., and Manne, A. S., "Energy-Economic Interactions: The Fable of the Elephant and the Rabbit ?", Working Paper EMF 1.3, Energy Modeling Forum, Stanford University, Stanford, Calif., July 1977. Found in Appendix B.

3 Sources for Figure 1. The GNP data in 1972 dollars are taken from the Economic Report of the President, 1977. The energy quantity data are from the Bureau of Mines. Primary energy prices are taken as the price of crude oil equivalent from Energy Perspectives, 1975, of the Department of Interior.

4 The elasticity of demand is defined here in terms of primary energy prices. This complicates the direct comparison of elasticity estimates from other studies due to definitional and aggregation problems. However, representative estimates for energy demand can be found in: M. L. Baughman and P. L. Joskow, "Energy Consumption and Fuel Choice by Residential and Commercial Consumers in the United States", MIT Energy Laboratory, May 20, 1975; Federal Energy Administration, National Energy Outlook, Appendix C, Feb. 1976; W. D. Nordhaus, "The Demand for Energy: An International Perspective", Cowles Foundation Discussion Paper 405, Yale University, New Haven, Conn., Sept. 1975.

5 The economic impacts of the simple model with a constant return on capital are developed for the full range of elasticity assumptions and energy input reductions in Appendix B.[2] The complete dynamic general equilibrium analysis of the sophisticated models is required to analyze fully the capital-energy interactions. As an approximation, however, the ad hoc assumption of a constant rate of return can be viewed as appropriate for the comparison between two steady state balanced growth paths, where the rate of return is constant. This issue is discussed at greater length in Appendix C: W. W. Hogan, "Capital-Energy Complementarity in Aggregate Energy-Economic Analysis", Working Paper EMF 1.10, Energy Modeling Forum, Stanford University, Stanford, Calif., Sept. 1977. Found in Appendix C.

6 Hogan, W. W., and Parikh, S. C., "Comparison of Models of Energy and the Economy", Working Paper EMF 1.4, Energy Modeling Forum, Stanford University, Stanford, Calif., May 1977. Found in Appendix D.

7 "Driving Variables, Scenario Definitions, and Individual Model Exceptions", Working Paper EMF 1.2, Energy Modeling Forum, Stanford University, Stanford, Calif., June 1977. Found in Appendix F.

8 Data from the results of the EMF model comparison, Appendix F.