



EMF REPORT 4
Volume 1
August 1980

Aggregate Elasticity of Energy Demand

Volume 1

becom • epm • mefs

besom/hudson-jorgenson

jackson commercial

baughman-joskow • fossil1

fea-faucett • eta-macro

hirst residential • griffin oecd

wharton move

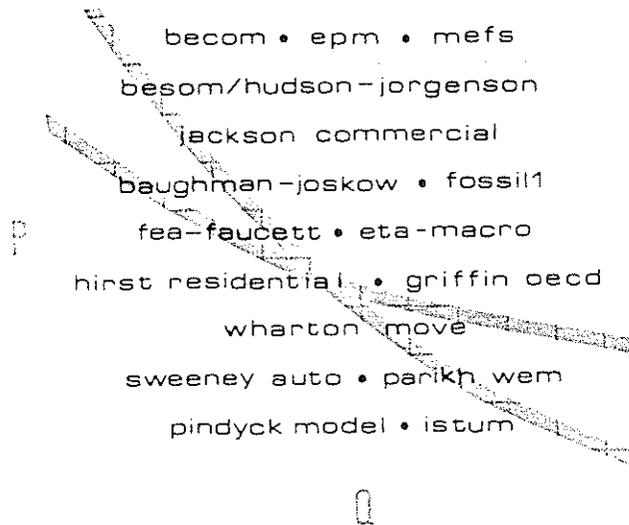
sweeney auto • parikh wem

pindyck model • istum

Q

ENERGY MODELING FORUM

AGGREGATE ELASTICITY OF ENERGY DEMAND



EMF Report 4

Volume 1

August 1980

Energy Modeling Forum
Stanford University
Stanford, California 94305

LEGAL NOTICE

This report was prepared by the Energy Modeling Forum (EMF), administered by the Institute for Energy Studies, Stanford University, as an account of work sponsored by the Electric Power Research Institute, Inc. (EPRI). Neither EPRI, members of EPRI, EMF, nor any person acting on behalf of either: (a) makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

This report summarizes the results of the EMF working group study. It does not necessarily represent the views of Stanford Institute for Energy Studies or Stanford University.

EXECUTIVE SUMMARY

AGGREGATE ELASTICITY OF ENERGY DEMAND

The response of energy demand to changes in energy prices is central to the evaluation of energy policies. To study this response, analysts and modelers have developed many sophisticated models of energy demand. These models, differing in their structure and degree of detail, do not lend themselves to easy comparisons of the relationship between demand and prices.

Simplified to a single number, the response of demand to changes in price can be described as an elasticity. The aggregate price elasticity of energy demand is equal to the percent reduction in energy demand produced by a 1 percent increase in energy price, with all else held constant. This definition of elasticity is presented graphically in Figure 1. By convention, aggregate elasticities are positive whenever price increases lead to a decrease in demand.

Straightforward in concept, the aggregate elasticity of demand for energy is elusive in practice. However, there is an appeal to this simple single parameter as an indicator of important underlying relationships. There is little doubt that analysts will continue to use this single elasticity to describe aggregate changes in future energy demand. If it is to be used correctly, there must be an improvement in its definition and measurement. The present report works towards this end by summarizing results from the Energy Modeling Forum (EMF) comparison of energy demand models.

The goal of this study is the description of the aggregate price elasticity of demand implicit in energy demand models. An EMF working group conducted experiments with 16 detailed models of the energy sector. The group developed consistent estimates of the 15-, 25-, and 35-year energy demand elasticities implicit in each of the models. The comparison of results is descriptive; there was no attempt to produce a single best estimate of the demand elasticity.

The aggregate elasticity or the set of fuel-specific elasticities is critically important for many analyses. The higher the elasticity of demand for energy, the smaller will be the impact on GNP (gross national product) of a given reduction in the quantity of energy available, and the smaller will be the impact of a given increase in the cost of imported energy. The higher the elasticity, the lower will be the forecasted future consumption of energy in high price situations, the less urgent will be the perceived need for energy supply technologies, and the lower will be projected world oil prices.

Since energy includes a number of heterogeneous commodities, each with a separate price, these prices and quantities must be aggregated in order to calculate a single elasticity. The choice of aggregation rules can influence the resultant estimations. The group examined several alternative indexes for the aggregation: Paasche, Laspeyres, Tornquist, and Btu-weighted. Similarly, the elasticity can vary by a factor of nearly two over different stages from production to consumption. The group compared two standardized points of measurement:

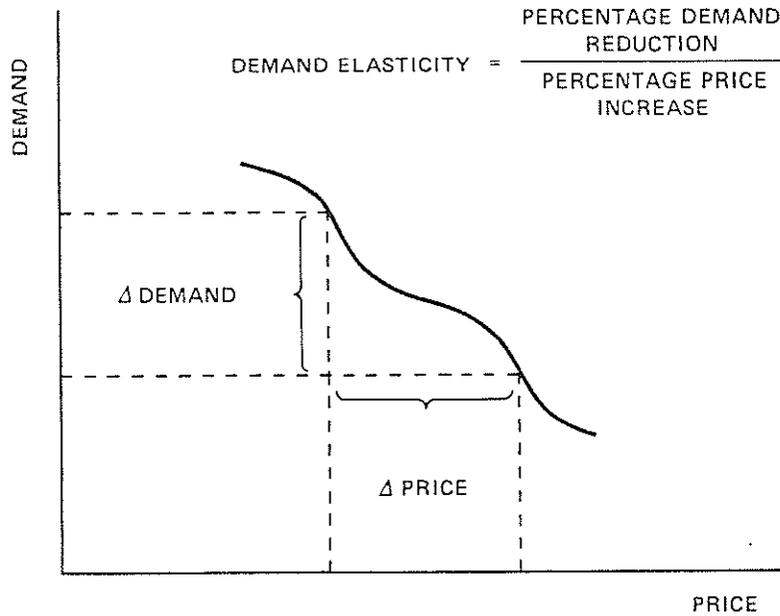


Figure 1 Elasticity Definition

- primary energy, measured directly before refining, electricity generation, and synthetic fuels conversion losses; and
- secondary energy, measured directly after conversion and refining losses.

Primary energy prices are generally lower and quantities are higher than for the corresponding secondary values; consequently, the primary elasticities will be generally lower than the secondary elasticities.

Total demand for energy can adjust in many ways. The detailed energy demand models focus on different system elements, possibly fixing some demands while calculating others. Some of the models include restrictions which reduce the ability of the economy to adjust to higher prices or which reduce the measured elasticity. Additionally, disaggregated elasticities may be estimated statistically or by other approaches, i.e., engineering or judgmental.

The working group addressed the above and other issues to conclude:

- 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, were generally characterized by the highest implicit aggregate secondary demand elasticities. 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.

- As shown in Table 1, demand elasticities vary significantly across sectors, among models, and among assumed policy regimes. Automobile efficiency standards, for example, may lower the elasticity for gasoline by a factor of 2 to 3.
- Aggregate elasticity estimates were not sensitive to the choice of Paasche, Laspeyres, or Tornquist indexes but differed when the Btu-weighted index was chosen. Because the Btu-weighted index is theoretically less attractive, the Paasche index is used in this summary.
- The aggregate demand changes projected with many models were sensitive to the specific composition of price changes. Since an aggregate analysis may be inadequate or misleading for these models, a method was developed to illustrate the implications of different compositions of price changes.
- The study did not examine the adjustment dynamics inherent in the models. However, energy demand adjustments occur slowly since demand is linked to the stock of energy-using equipment. Analysis of the post-1973 experience indicated that the conservation actually experienced to date could be consistent with any of the estimated long-run primary energy elasticities implicit in the models.
- There is a range of uncertainty associated with any demand elasticity estimate; the actual elasticity could be greater than or less than any of the point estimates presented here. The range of uncertainty is not the same as the range of elasticity estimates. Several sources of uncertainty exist in each model: measurement error in the data,

Table 1

25-YEAR SECONDARY DEMAND ELASTICITY ESTIMATES

Sectors	Parameter Estimation Methodology	
	Statistical	Other Approaches (Engineering or Judgmental)
All Sectors	0.3-0.7	0.1-0.6
Residential	0.5-1.0	0.4
Residential/Commercial	0.5-0.8	0.5
Commercial	0.5	0.3-0.4
Commercial/Industrial	0.3-0.7	0.1
Industrial	0.2-0.5	0.2-0.7
All Transportation	0.2-0.5	0.4
Automobile Gasoline		
with Efficiency Standards	0.1-0.2	--
without Efficiency Standards	0.1-0.5	--

parameter estimation uncertainty, and model specification errors. However, limitations in the current state of the art either preclude calculation of explicit uncertainty measures or make calculation extremely costly.

- Measurement of prices and quantities at the secondary energy level was more useful for computing dependable aggregate elasticities than measurement at the primary level. The conditions necessary to insure the theoretical consistency of aggregate economic indexes are more nearly satisfied at the secondary level. Additionally, most demand models are structured in terms of delivered energy, which can be adjusted easily to the secondary energy level; more arbitrary procedures were required to adjust data to the primary energy level.
- The elasticities differ due in part to differences in modeling approaches, techniques, or assumptions. Detailed models often represent some components of energy demand as independent of price, thereby biasing downward the calculated aggregate elasticity. Engineering process models may exclude unrecognized technological options and may underestimate the substitution flexibility of the economy.

Based upon its findings, the working group recommends the following:

- The Energy Information Administration (EIA) of the U.S. Department of Energy, working in close coordination with modelers, should develop consistent accounting conventions and standardized data for demand analysis. The working group spent a great deal of time on standardizing the data without fully succeeding.
- Modelers should improve their practice in publishing assumptions, error statistics, robustness tests, validity tests, descriptive information, and historical data supporting their models. Agencies funding model development should insist on and support this effort.
- Modelers should make aggregate elasticities, whether explicit or implicit, a standard component of the documentation of demand models. The EIA should publish a set of definitions and computational procedures for calculating these elasticities and the associated adjustment time lags.
- Modelers should develop and then consistently utilize techniques for describing the uncertainties in their models. This will require basic research to develop the methodology. Funding organizations and modelers, realizing that analysis of uncertainties is costly but important; should budget sufficient funds for this activity.

TABLE OF CONTENTS

	<u>Page</u>
Volume 1: Executive Summary	iii
Acknowledgments	ix
Senior Advisory Panel	xi
Working Group Participants	xii
EMF Staff Contributors	xiii
Chapter 1: Aggregate Elasticity of Energy Demand	
Introduction	1
Significance of Elasticities	3
Issues in Computing Aggregate Elasticities	6
Overview of the Models	19
The Experimental Design	23
Conclusions	25
Recommendations	41
Volume 2: Chapter 2-13	
2. The Design of the Experiment, W. W. Hogan, J. P. Weyant, and D. R. Fromholzer	2-1
3. Model Comparison, J. P. Weyant, T. F. Wilson, and J. L. Bower	3-1
4. The Theory and Practice of Energy Aggregation, A. B. Borison, J. L. Sweeney, and T. F. Wilson	4-1
5. Energy System Elasticities, D. Nissen	5-1
6. The Data Base for Elasticity Estimates, T. F. Wilson and S. V. Duvall	6-1
7. The Elasticity Estimates, T. F. Wilson and S. V. Duvall	7-1
8. Explaining Intermodel Differences, J. M. Griffin and D. O. Wood	8-1
9. Price and Quantity Change Decomposition for Aggregated Commodities, J. L. Sweeney	9-1
10. Quantification of Uncertainty in Elasticity Estimates Obtained from the Econometric Models, L. J. Lau	10-1
11. The Dynamics of Elasticity Estimation, D. R. Fromholzer and L. J. Lau	11-1
12. The Econometric Experiment of 1973, A. S. Manne and T. F. Wilson	12-1
13. Delivered Energy Demand Elasticities: Evidence from Recent Trends, W. W. Hogan	13-1

LIST OF TABLES

Volume 1

<u>Table</u>		<u>Page</u>
1	25-Year Secondary Demand Elasticity Estimates	v
2	Models Used in the Aggregate Elasticity of Energy Demand Study .	2
3	Parameter Estimation Approaches	23
4	Primary Energy Price Cases	25
5	Comparison of 25-Year Primary and Secondary Elasticity Estimates (Paasche Index)	26
6	Comparison of 25-Year Secondary Demand Elasticity Estimates Based on Selected Indexes	28
7	25-Year Secondary Demand Elasticities by Sectors (Paasche Index) .	31
8	25-Year Secondary Fuels Decomposition Results (Paasche Index) . .	35
9	25-Year Primary Fuels Decomposition Results (Paasche Index) . . .	37
10	15-Year Secondary Elasticity Estimates With and Without CAFE Standards	40

LIST OF FIGURES

Volume 1

<u>Figure</u>		<u>Page</u>
1	Elasticity Definition	iv
2	Relationship between Energy Price and the Energy/GNP Ratio as a Function of Aggregate Elasticity	5
3	Relationship between Energy Use and GNP as a Function of Aggre- gate Elasticity for the Excise Tax Case	5
4	Ratio of Retail and Secondary Elasticities as a Function of Secondary Energy Price	17
5	25-Year Total Demand Primary and Secondary Energy Price Responses for the MEFS and FOSSILL Models	27
6	Aggregate Total Demand Elasticity Estimates	29
7	25-Year Industrial Secondary Energy Index Values for the ISTUM Model	33
8	Comparison of 25-Year Secondary Energy Decomposition Results from the MEFS and Baughman-Joskow Models	34
9	Dependence of Long-Run Elasticity Estimates on Assumed One-Year Adjustment Parameter	38
10	Relationship between Energy Price and GNP as a Function of Aggregate Elasticity for the Cost Increase Case	44

ACKNOWLEDGMENTS

The fourth Energy Modeling Forum study, "Aggregate Elasticity of Energy Demand," was initiated as an experiment at the request of the Energy Modeling Forum Senior Advisory Panel at its 1977 annual meeting. The objective was to obtain improved information about aggregate elasticities of substitution between energy and other inputs in the economy. During the first EMF study, "Energy and the Economy," this parameter was identified as being fundamental in estimating the relationship between reduced availability of energy and economic growth. A study design was developed and modelers were asked to exercise their energy demand models along the study specifications.

During the course of the study, it became apparent that issues of interpretation were fundamentally important and that the initial plan to conduct the study as an experiment without any working group meetings would not be feasible. Therefore, two meetings were held, the first at the John F. Kennedy School of Government at Harvard University and the second at the University of Chicago, hosted respectively by William Hogan and Thomas Long. Working group members participating in the study and these meetings are listed on page xii. Most of the issues dealt with in this report were debated during those meetings. Most subsequent work was conducted by members of the working group and the Energy Modeling Forum staff. This work is reflected in both the summary report (Volume 1) and the more complete report (Volume 2).

Many people made important contributions throughout the study. John Weyant served as study coordinator and in this regard played major roles in drafting the study design and the summary report, held primary responsibility for the writing of several chapters, and supervised the EMF staff effort. Tom Wilson held initial responsibility for developing the software that made the model comparison possible and also was responsible for some of the chapter writing. The final computer graphics work was conducted by Steve Duvall.

An extensive amount of work was conducted by the various researchers whose models were exercised in the study. Individuals responsible for running models included Martin Baughman, Phillip Budzik, Ronald Cooper, Richard Goettle, James Griffin, Eric Hirst, Jerry Jackson, Dilip Kamat, Damian Kulash, Colin Loxley, Alan Manne, Shirish Mulherkar, Roger Naill, Shailendra Parikh, Robert Pindyck, and Geoffrey Ward.

Extensive work also was conducted by the various chapter authors, listed in the table of contents.

Besides working group members, Senior Advisory Panel members contributed significantly through their initial identification of the study topic, their assistance in identifying working group members, and through their reviews of the report. We would like to particularly thank Harvey Brooks, Floyd Culler, Herman Dieckamp, Joseph Fisher, Henry Linden, Chauncey Starr, and Robert Wycoff for their comments on the final report as it went through the review process.

We would also like to thank Nancy Silvis for her imaginative editorial and graphic work and painstaking preparation of the manuscript for publication. As editorial consultant, Dorothy Sheffield proved invaluable. Pamela Rosas and Janice Evans were responsible for preparing seemingly endless preliminary drafts of the summary report and the various chapters.

Primary financial support for this study was provided by the Electric Power Research Institute. Several participating institutions assisted further by underwriting the cost of running the models under the various scenarios and/or by underwriting transportation costs of members to the meetings. These include the Brookhaven National Laboratory, Congressional Budget Office, Energy and Environmental Analysis, Inc., Lawrence Livermore Laboratory, Massachusetts Institute of Technology, Oak Ridge National Laboratory, Stanford University, U.S. Department of Energy, University of Chicago, University of Houston, and University of Texas.

William Hogan
Working Group Chairman

James Sweeney
EMF Director

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 policymakers, 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 investigations, critiques the studies, guides the operations of the project, and helps communicate the results to the energy policymaking community. The role of the Panel is strictly advisory. The Panel is not responsible for the results of the individual EMF working group studies.

Dr. Harvey Brooks, Chairman	Professor, Harvard University
Dr. Philip Abelson	Editor, <u>Science</u> , American Academy for the Advancement of Science
Mr. David Cohen	President, Common Cause
Mr. Gordon R. Corey	Vice Chairman, Commonwealth Edison
Dr. Floyd L. Culler, Jr.	President, Electric Power Research Institute
Mr. Charles Di Bona	President, American Petroleum Institute
Mr. Herman M. Dieckamp	President, General Public Utilities Service Corporation
The Honorable John Dingell	Member, U.S. House of Representatives
The Honorable Joseph Fisher	Member, U.S. House of Representatives
Mr. Charles J. Hitch	President Emeritus, University of California
The Honorable William Hobby	Lieutenant Governor of Texas
Mr. Jack K. Horton	Chairman, Southern California Edison Company
Dr. William Lewis	Assistant Secretary for Policy and Evaluation, U.S. Department of Energy
Dr. Henry R. Linden	President, Gas Research Institute
Mr. Guy W. Nichols	President, New England Electric System
Mr. John F. O'Leary	Energy Consultant, Ralph Snyder Associates
Dr. Alan Pasternak	Energy Consultant
Dr. Chauncey Starr	Vice Chairman, Electric Power Research Institute
The Honorable Morris Udall	Member, U.S. House of Representatives
Mr. Robert E. Wycoff	Senior Vice President, Atlantic Richfield Company

WORKING GROUP PARTICIPANTS

George Backus	Dartmouth College
Martin Baughman	University of Texas
Robert D. Belden, Jr.	Harvard University
Roger Bohn	Massachusetts Institute of Technology
Phillip Budzik	U.S. Department of Energy
Ronald Cooper	Lawrence Livermore Laboratory
V. J. Duggal	Wharton Econometric Forecasting Associates
Richard Goettle	Dale Jorgenson Associates, Inc.
Martin Greenberger	The Johns Hopkins University
James Griffin	University of Houston
Eric Hirst	Oak Ridge National Laboratory
William Hogan	Harvard University
John Holte	U.S. Department of Energy
Frank Hopkins	U.S. Department of Energy
Edward Hudson	Dale Jorgenson Associates, Inc.
Jerry Jackson	Georgia Institute of Technology
Dale Jorgenson	Harvard University
David Knapp	Chase Manhattan Bank
Damian Kulash	Congressional Budget Office
Lawrence Lau	Stanford University
Thomas Long	University of Chicago
Joan Lukachinski	Brookhaven National Laboratory
Alan Manne	Stanford University
William Marcuse	Brookhaven National Laboratory
Roger Naill	U.S. Department of Energy
David Nissen	Chase Manhattan Bank
Shailendra Parikh	Oak Ridge National Laboratory
Stephen Peck	Electric Power Research Institute
Robert Pindyck	Massachusetts Institute of Technology
J. Michael Power	U.S. Department of Energy
Robert Reid	Energy and Environmental Analysis, Inc.
William Rousseau	Lawrence Livermore Laboratory
George Schink	Wharton Econometric Forecasting Associates
James Sweeney	Stanford University
Lester Taylor	University of Arizona
Geoffrey Ward	Massachusetts Institute of Technology
John Weyant	Stanford University
Chris Whipple	Electric Power Research Institute
David Wood	Massachusetts Institute of Technology

EMF STAFF CONTRIBUTORS

James L. Sweeney, EMF Director
John P. Weyant, Study Coordinator

Adam Borison	Dennis Fromholzer
J. Lindsay Bower	Pamela Rosas
Steven Duvall	Dorothy Sheffield
Janice Evans	Nancy Silvis
Elizabeth Farrow	Patricia Ward
Mary Fenelon	Thomas Wilson

Chapter 1

AGGREGATE ELASTICITY OF ENERGY DEMAND

INTRODUCTION

EMF 1 identified the importance of the aggregate elasticity of energy demand:

The first EMF study, "Energy and the Economy," produced estimates of the aggregate elasticity of substitution for primary energy implicit in six models of energy and the economy.¹ In that study, the working group identified the importance of the aggregate elasticity and called for an examination of more detailed demand models. During its review of the study, the EMF Senior Advisory Panel cited the importance of a careful investigation of energy demand models to clarify estimates of the aggregate elasticity. The present study is a response to those suggestions.

the percent decrease in demand produced by a 1 percent increase in price.

The aggregate price elasticity of energy demand is the percent reduction in energy demand produced by a 1 percent increase in energy price, with all else held constant. By convention, aggregate elasticities are positive whenever price increases lead to decreases in demand.²

Aggregate demand elasticities were estimated for 16 energy models but no single best estimate was identified.

The working group conducted experiments with 16 detailed models of the energy sector. Table 2 provides a complete listing of the models. The uncertainty in the current state of the art is emphasized. This group made no attempt to produce a single best estimate of the demand elasticity; at a minimum, the study provides simple summary statistics for comparing energy demand models. In addition, the results suggest the limitations of an aggregate model of energy demand for some applications and, therefore, reinforce the need for more detailed models of energy use.

Table 2

MODELS USED IN THE AGGREGATE ELASTICITY OF
ENERGY DEMAND STUDY

Energy-Economy Models

Brookhaven Energy System Optimization Model/Hudson-Jorgenson
(BESOM/H-J), Brookhaven National Laboratory and Dale
Jorgenson Associates
Energy Technology Assessment-MACRO (ETA-MACRO), Alan Manne,
Stanford University
Parikh Welfare Equilibrium Model (Parikh WEM), Shailendra
Parikh, Stanford University

Energy System Models

Baughman-Joskow (Baughman-Joskow), Martin Baughman and Paul
Joskow, University of Texas
Energy Policy Model (EPM), Lawrence Livermore Laboratory
FOSSIL1 (FOSSIL1), Dartmouth System Dynamics Group, Dartmouth
College
Griffin Organization for Economic Cooperation and Development
(Griffin OECD), James Griffin, University of Houston
Mid-Range Energy Forecasting System (MEFS), U.S. Department
of Energy
Pindyck International Study (Pindyck), Robert Pindyck,
Massachusetts Institute of Technology

Sectoral Models

Buildings Energy Conservation Optimization Model (BECOM),
Brookhaven National Laboratory
Federal Energy Administration-Faucett (FEA-Faucett), Carmen
Difiglio and Damian Kulash, Federal Energy Administration
Industrial Sector Technology Use Model (ISTUM), Energy and
Environmental Analysis, Inc.
Jackson Commercial (Jackson Commercial), Jerry Jackson,
Oak Ridge National Laboratory
The ORNL Residential Energy-Use Model (Hirst Residential),
Eric Hirst and Janet Carney, Oak Ridge National Laboratory
Sweeney Automobile Model (Sweeney Auto), James Sweeney,
Stanford University
Wharton Motor Vehicle Model (Wharton MOVE), Wharton Econometric
Forecasting Associates

The remainder of this report

- establishes the significance of elasticities in energy policy and planning,
- identifies some key issues to be addressed in computing aggregate elasticities,
- gives an overview of the models employed in the study,
- describes the experimental design for estimating the aggregate elasticity implicit in each model,
- reports the study results, and
- makes recommendations.

SIGNIFICANCE OF ELASTICITIES

Demand elasticity estimates are crucial to energy policy analyses.

The aggregate elasticity of energy demand or the set of fuel-specific elasticities is critically important for many analyses, such as forecasts of future energy consumption, evaluations of the appropriate timing of energy technology development, assessments of energy tax policies, and predictions of OPEC (Organization of Petroleum Exporting Countries) pricing strategies. The higher the price elasticity of demand for energy, the greater will be the impact on GNP of a given tax on energy, the smaller will be the impact of a given reduction in the quantity of energy available, and the smaller will be the impact of a given increase in the cost of imported energy.³ 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 perceived need for new energy supply technologies, and the lower will be projected world oil prices.

Aggregate elasticities are more easily understood and communicated than are detailed elasticities.

Detailed elasticities by fuel and sector are important for many of these same analyses, and a full-scale analysis of a particular policy may depend upon the use of detailed models. But detailed model differences and their implications may be difficult to perceive and communicate. Aggregate elasticity calculations provide simple summary parameters that are easily understood and used. And since many energy prices tend to increase together, aggregate elasticities give a rough estimate of the magnitude

of the energy consumption changes resulting from pervasive changes in the energy situation, such as those caused by increases in world oil prices. These rough estimates may be adequate for many purposes.

The projected ratio of energy use to GNP depends upon the aggregate demand elasticity.

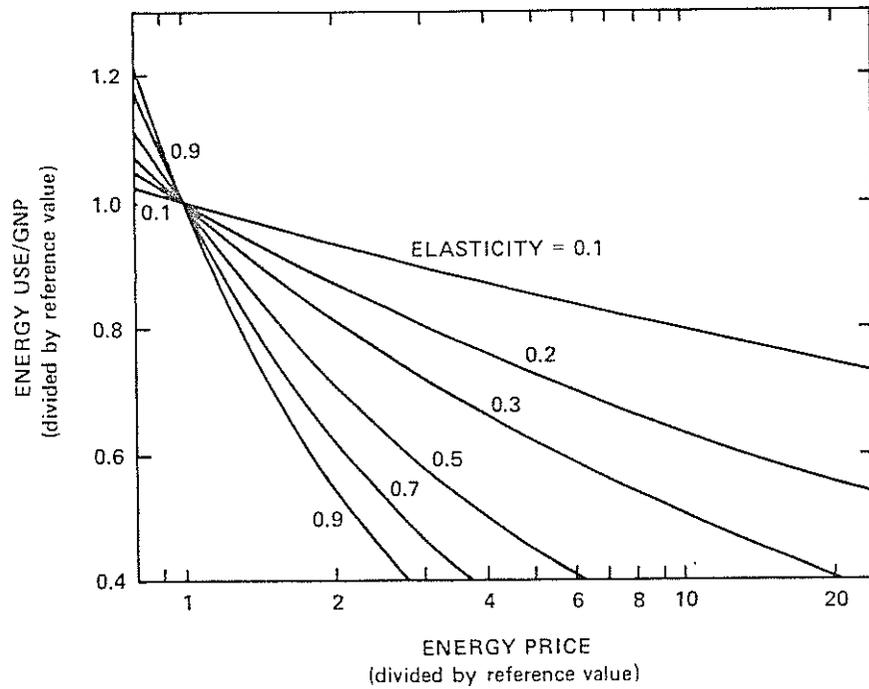
One simple use of aggregate elasticity estimates is the calculation of the extent to which energy consumption can be reduced in response to increasing energy prices or costs. The consumption reduction depends upon the reduction in aggregate economic activity and the ability of actors in the economy to substitute other inputs for energy. However, the ratio of energy use to GNP depends primarily upon the ability of the economy to substitute capital and labor inputs for energy, as measured by the aggregate elasticity of demand.

The higher the elasticity, the smaller the price increase required to reduce the energy/GNP ratio a given amount.

Figure 2 illustrates the ratio of future energy use to GNP as a function of energy price for demand elasticities ranging from 0.1 to 0.9. The coordinates are standardized at unity by dividing by Reference values in order to facilitate examination of fractional changes in the ratio. If the long-run elasticity of demand for energy is as low as 0.1, a 10-fold increase in energy prices is required to ultimately reduce the energy/GNP ratio by 20 percent. However, if the elasticity is as high as 0.9, the same 20 percent reduction in the energy/GNP ratio can be achieved by a 28 percent increase in energy price. Thus, forecasts of future energy consumption and analyses of the efficacy of conservation programs in reducing energy demand depend upon the aggregate price elasticity.

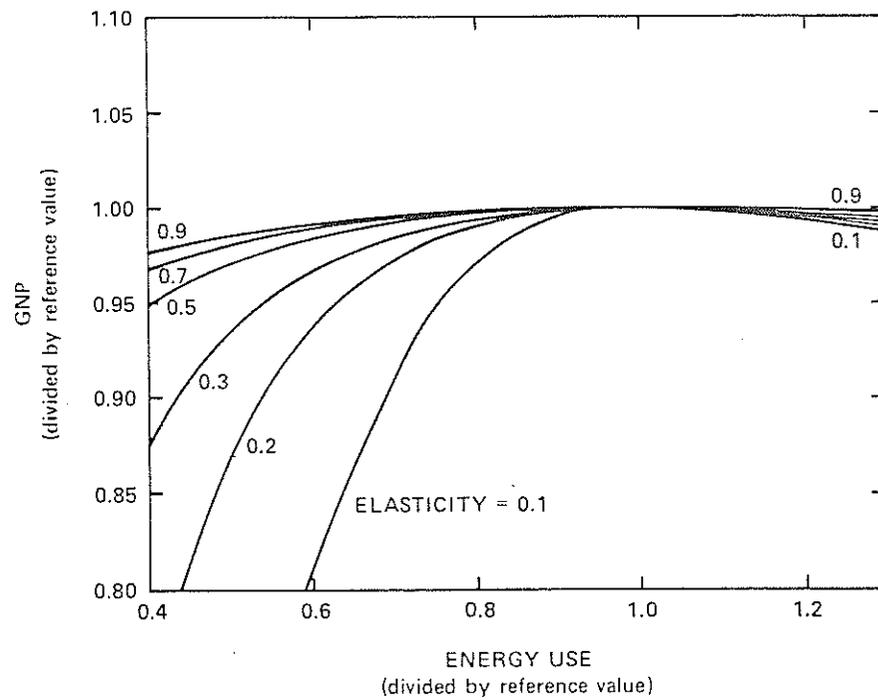
The aggregate elasticity is important in estimating the economic costs of reductions in energy use.

Results from analysis with a simple aggregate model of energy-economy interactions demonstrate the importance of the elasticity of energy demand or the closely related elasticity of substitution between aggregate energy and other inputs, i.e., capital and labor.^{4,5} Figure 3 illustrates, for various values of the aggregate elasticity, the relationship between the GNP and energy use in this model.⁶ The results demonstrate the importance of the elasticity of energy demand in determining the magnitude of the macroeconomic impacts of reductions in energy use. If the



Note: Energy use and price measured at secondary level

Figure 2 Relationship between Energy Price and the Energy/ GNP Ratio as a Function of Aggregate Elasticity



Note: Energy use and price measured at secondary level

Figure 3 Relationship between Energy Use and GNP as a Function of Aggregate Elasticity for the Excise Tax Case

long-run demand elasticity were 0.2, a 50 percent reduction in secondary energy inputs, motivated by measures which increase consumers' energy prices but not resource costs, such as a Btu (British thermal unit) tax, would ultimately lead to a 13 percent reduction in GNP each year. If the elasticity were 0.7, this same 50 percent reduction in secondary energy inputs would lead to only a 3 percent reduction in GNP.

The larger the elasticity, the smaller the long-run economic impacts of reduced energy availability.

These results have important implications for both energy policy and the validity of energy sector models. For example, if the demand elasticity were low, say 0.1 to 0.2, changes in energy availability could have major long-run economic effects. With such large feedbacks, one may question the logical consistency of models which take the GNP as given (partial equilibrium models). On the other hand, if the demand elasticity were high, say 0.6 to 0.7, changes in energy availability could be substantially decoupled from long-run economic growth, lending credibility to the partial equilibrium approach for analyses of conservation programs or tax measures.

ISSUES IN COMPUTING AGGREGATE ELASTICITIES

Many methodological problems were addressed.

The design and implementation of the study presented a number of methodological and definitional problems. The following issues were found to be particularly significant:

- distinctions between aggregate and single-fuel elasticities,
- aggregation of heterogeneous fuels,
- choice of index,
- composition of price change,
- standardization of aggregate economic activity,
- selection of measurement point,
- examination of dynamics, and
- characterization of uncertainty.

Aggregate Elasticities Versus Elasticities for Single Fuels

Energy price increases motivate inter-fuel and factor substitutions.

In response to an increase in the price of a single fuel, the demand for that fuel decreases as firms and individuals substitute other nonenergy products (factor substitution) and other energy forms (interfuel substitution) in place of the fuel whose price has increased. The interfuel substitution leads not only to decreases in the demand for the more costly fuel but also to increases in the demands for competing fuels. As a result, aggregate energy demand is reduced by less than the demand for a single fuel.

The elasticity of demand for specific fuels normally exceeds the aggregate demand elasticity.

The percentage decrease in the demand for a single fuel as its price increases by 1 percent, holding other prices constant, is its "own elasticity" of demand. The "cross elasticity" of demand is defined as the percentage increase in one fuel's demand when the price of a competing fuel is increased. The aggregate demand elasticity for energy is defined as the percentage reduction in aggregate demand in response to a 1 percent increase in aggregate price. For individual fuels, the aggregate elasticity of demand is generally smaller than the own elasticity of demand.

These points can be illustrated by a simple numerical example. Assume two types of energy with demands represented by E_1 and E_2 . Their prices, P_1 and P_2 , are related by the following linear inverse demand functions:

$$E_1 = 1.2 - P_1 + 0.8 P_2, \text{ and}$$

$$E_2 = 1.2 - 0.8 P_1 - P_2 .$$

Total energy demand (E_T), the sum of E_1 and E_2 , is

$$E_T = 2.4 - 0.2 P_1 - 0.2 P_2 .$$

Suppose that $P_1 = P_2 = 1$, then $E_1 = E_2 = 1$ and $E_T = 2$.

Failure to distinguish between the two elasticity concepts can lead to misapplication.

In the above example, a 10 percent increase in P_1 , from 1 to 1.1, reduces the demand for energy type 1 by 0.1 units or 10 percent: the fuel-specific own elasticity of demand is 1.0. However, the demand for energy type 2 is simultaneously increased by 8 percent, a cross elasticity of 0.8, leading to a net decrease in total energy demand of 0.2 units or 1 percent. Since the average price of energy increases by 5 percent, the aggregate demand elasticity equals 0.2.⁷ Similarly, a 10 percent increase in both prices implies a 10 percent increase in average price and a decrease in aggregate demand by 0.04 units or 2 percent. The aggregate demand elasticity is again calculated to be 0.2. This aggregate elasticity of 0.2 can be compared with the fuel-specific own elasticity of 1.0. Failure to distinguish clearly between the two concepts can easily lead to misapplication of estimated demand elasticities.

The Aggregation Problem

Prices and quantities of individual fuels must be aggregated.

Aggregate elasticity estimations require alternative projections of aggregate energy and its price. However, aggregate energy is neither marketed in the real world nor represented directly in the detailed energy demand models. Consequently, any scheme for measuring the aggregate price elasticities implicit in the models depends upon a rule for aggregating prices and quantities of individual energy products.

The choice of a particular aggregation rule can affect the results.

In the above example, aggregation consisted of adding total energy use and averaging prices. This natural scheme is one of many possible aggregation rules. Furthermore, adding quantities and averaging prices leaves open the question of what units to use: physical weight, economic value, Btus. If economic value is the unit to be used in aggregating, one must choose the prices to use in calculating economic value. If prices are changing, the choice is not obvious. If Btus are used, one must specify how to measure Btus: heat value under perfect combustion, heat value under combustion with normal utilizing equipment, or heat value of the raw materials used to produce the final energy commodity.⁸

The aggregation problem can be illustrated by an example.

The importance of the aggregation problem is illustrated by further use of the example. Assume energy type 1 is electricity, type 2 is natural gas, and the units used above are measured in terms of delivered Btus, output or delivered energy. Alternatively, one may aggregate by the Btus required to generate the final product (primary energy). To aggregate in terms of primary energy, all coefficients in the first equation must be multiplied by three.⁹

The new equations are

$$E1' = 3.6 - 3.0 (3P) + 2.4 P2$$

$$E2 = 1.2 + 0.8 (3P) - P2 ,$$

where P, the price of electricity inputs, equals 1/3 P1 and

$$ET' = 4.8 - 2.2 (3P) + 1.4 P2 .$$

Now, if P1 = P2 = 1, then E1' = 3, E2 = 1, and ET' = 4.

Two methods of aggregation were considered.

For this example, a 10 percent increase in electricity price increases the average price of output energy by 5 percent and reduces total demand for primary energy by 5.5 percent, yielding an aggregate elasticity equal to 1.1. A 10 percent increase in the price of natural gas increases average delivered price by 5 percent and increases total energy input demand by 3.5 percent, yielding an aggregate demand elasticity of -0.7. Hence, a seemingly simple change of the units used in the aggregation can change the magnitude and even the sign of the implicit aggregate demand elasticity. Two approaches to the aggregation problem were considered: (1) estimating a production or demand function for aggregate energy and (2) using price and quantity indexes for energy.

Estimating a production function for aggregate energy required too much data.

One way to approach the aggregation problem is to postulate the existence of a production function for energy with individual fuels being the inputs or, equivalently, to postulate a unit-cost function with the price of aggregate energy determined by component fuel prices. The production function formulation of

the aggregation problem has a strong theoretical foundation, for example, the description in Diewert.¹⁰ The equivalent unit-cost function approach is prevalent in energy-economy models, for example, in the work of Hudson and Jorgenson.¹¹ However, the production/unit-cost function approach to the problem of computing the price and quantity of aggregate energy requires far more information than needed to determine the price elasticity for aggregate energy. A more economical and direct approach was needed.

Therefore, index numbers were used.

The use of index numbers provides a short cut for determining the aggregates directly from their components, without having to statistically estimate the full aggregation rules. Index numbers provide an approximation to the production function and in some special cases can be exact. The index number approach is developed more fully in Volume 2 Chapters 2 and 4.

The Choice of Index

Most indexes, except the Btu-weighted, are consistent with optimizing behavior.

Many different index formulas can be used to aggregate the data provided by the models, and different aggregators can result in different aggregate elasticities from the same data, as shown above. Several of the most commonly used indexes, Paasche, Laspeyres, Ideal, Tornquist, and Btu-weighted, were considered in this study. Except for the Btu-weighted, these indexes are consistent with the assumption of optimizing behavior on the part of producers and consumers.

The Laspeyres, Paasche, and Ideal indexes use prices and quantities as weights for aggregation.

The familiar Laspeyres and Paasche indexes correspond precisely to the examples above if the units correspond to economic value. Both quantity indexes are constructed by summing economic values (price times quantity) of energy consumed; both price indexes are constructed by averaging prices of energy consumed, using quantities as weights. The Laspeyres quantity index uses price weights corresponding to the Reference case or base year; the Paasche quantity index uses price weights corresponding to the specific scenario or the current year. In a similar manner, the Laspeyres price index uses Reference case or base year quantities

for averaging, while the Paasche price index uses specific scenario or current year quantities. The "Ideal" index is the geometric mean of the Laspeyres and Paasche indexes.

These indexes produce approximations to the aggregate production function.

Each of the three indexes, Laspeyres, Paasche, and Ideal, provides an approximation to the quantity and average prices obtainable from an aggregate production function or cost function. The approximation from the Reference case levels is very close for infinitesimal changes in price and quantity. For larger changes, however, the approximation becomes less exact.

And for small price changes, four indexes yield identical results.

The more complex Tornquist index has been developed to provide an exact calculation for large price and quantity changes. The Tornquist index is exact for all possible prices under the special assumption that the unit-cost function is quadratic in logarithms of energy input prices (a "transcendental logarithmic function").¹² For small price and quantity changes, all four indexes are identical to one another. Thus, the aggregate elasticities calculated with the four indexes will be similar.

Although used pervasively, the Btu-weighted index has serious theoretical shortcomings.

The last index considered, Btu-weighted, is not based on the assumption of optimizing behavior by economic agents but, rather, on an implicit assumption that all energy forms are perfect substitutes on a Btu basis. Despite its theoretical shortcomings, this index was included here because of its pervasive use in aggregate energy accounting. This quantity index is simply the quantity sum over the various fuels, with units corresponding to the heat content (Btu) of the fuels. The price index is the average of the prices, weighted by Reference case quantities.

The Composition of Price Change

The aggregate elasticity can depend on the composition of price change.

Whenever heterogeneous commodities are aggregated, calculated aggregate demand elasticities may depend upon specific price changes. The elasticity can be positive or negative depending upon the mix of price changes: in the earlier example, aggregate price increases led to aggregate quantity decreases or increases, depending upon the price change composition. The example can be expanded to examine a 10 percent increase in the price of commodity

1 coupled with a 10 percent decrease in the price of commodity 2. In this case, the average price remains unchanged while the aggregate demand for primary energy is reduced by 9 percent. Since aggregate demand changes while aggregate price remains constant, even the concept of a demand function is questioned for aggregated commodities.

Average aggregate elasticity estimates may be sample-dependent.

When several different price changes are considered, an average elasticity can be calculated. However, this does not avoid the problem. If elasticities depend upon the composition of price changes, the average elasticity will depend upon the sample of price changes selected for the calculation.

The extent to which the price change composition affects the aggregate elasticity is important.

For some cases, the choice of an appropriate index will eliminate the problem. In general, however, there is no assurance that any index will allow the measured elasticity to be independent of the precise configuration of price changes. The relevant issue is not whether the price change composition matters but how significantly the composition problem influences measured results. Equivalently, the issue may be posed as one of determining the range of price-change directions over which a particular aggregate elasticity estimate approximately describes the aggregate behavior of the energy demand model.

The composition of price changes greatly affects the elasticity calculated for some models but not for others.

Sweeney, in Volume 2 Chapter 9, has developed a decomposition approach in the context of the present study. The decomposition method is based upon a simple but important observation: when an aggregated class of commodities is considered, a single-valued demand function for the aggregate may not even exist. The approach can be used to estimate an average elasticity for each model and index while preserving the notion that the calculated elasticity will, in general, depend upon the precise price change composition, as illustrated above. In such a situation, it is important to determine how nearly the relationship between quantity and price aggregates can be approximated by a single-valued demand function. This, then, provides the motivation for the decomposition method discussed more fully in Volume 2 Chapter 9. Because the decomposition technique is still experimental, it does not form the

basis of the summary tables or graphs in this report. Rather, a conventional averaging of elasticities has been utilized except where indicated.

Standardizing Aggregate Economic Activity

Increasing energy prices implies reductions in aggregate economic activity.

In response to increasing energy prices, one can expect pervasive changes in economic activity. Interfuel and factor substitutions imply shifts in the composition of economic output. Since energy is a factor of production in the economy, a reduction in energy use without corresponding increases in the availability of other productive factors implies a net reduction in the aggregate real value of goods and services produced in the economy. In fact, increases in the costs of importing or producing energy reduces the GNP even if the aggregate value of goods and services produced by the rest of the economy remains unchanged; as energy costs increase, more claims must be made against the output of the rest of the economy in order to import or produce a given quantity of energy. On the other hand, energy conservation strategies, such as energy-use taxes, may stimulate changes which lessen the economic impact of higher energy prices.

Higher energy prices affect energy demand both directly and indirectly through reductions in economic output.

For analytical purposes, it is useful to separate these various energy demand impacts into two components: (1) a demand response to higher price with aggregate economic activity held constant plus (2) a demand response to changed income or aggregate economic activity stemming from energy price or cost increases. The first component corresponds to the aggregate price elasticity of demand addressed in this study. The second component depends upon the income or economic activity elasticity of demand and the influence of energy system changes on aggregate economic activity. This last issue was the topic of the first EMF study and is not addressed further here.¹

The separation of price effects into two components typically varies by sector.

The precise manner of separating price effects into the two components typically varies among sectors being represented. For industrial sectors, the price elasticity is usually defined by holding constant the aggregate output from the particular sector. For the residential sector, disposable personal income is normally

held constant, while for the transportation sector either GNP or disposable income may be standardized.

The price elasticity of demand is defined holding constant either GNP or aggregate output from the energy-consuming sectors.

In order to define an aggregate price elasticity of demand, one must specify the measure of aggregate economic activity to be standardized. Two choices are natural: GNP or aggregate output of the energy-consuming sectors of the economy, referred to as the rest of the economy.¹³ This choice will influence the measured price elasticity of demand for energy. If GNP is held constant in defining the price elasticity, energy demand can be modeled as depending on GNP and a pure price effect. If aggregate output of the rest of the economy is held constant, energy is modeled as depending upon aggregate output and a pure price effect.

The calculated elasticity depends on this choice.

These two pure price effects generally differ in magnitude from one another. When demand reductions are motivated by price changes alone, e.g., taxes not coupled to cost changes, the price elasticity is generally larger if calculated by standardizing GNP than if calculated by standardizing the aggregate output of the rest of the economy. This occurs primarily because GNP declines less than aggregate output in response to energy price changes. Since that portion of the demand reduction modeled as working through economic activity is greater under the latter definition, the calculated pure price effect must be smaller if the sum of the two effects is to remain the same. In contrast, when the demand reduction is motivated by cost increases, the converse is true. In response to cost increases, GNP declines more than aggregate output. Therefore, the measured price elasticity based upon standardizing GNP is smaller than that based upon standardizing aggregate output.

This study standardized GNP.

This study examined responses to changes in the cost of producing or importing energy. The elasticities using both definitions were calculated, but the definition based upon standardizing GNP was adopted.

The Point of Measurement

Inconsistencies in the point of measurement are pervasive in the use of elasticities.

Since energy prices and quantities can be measured at many points in the energy system, inconsistencies in the point of measurement are pervasive in comparisons of the models. It is desirable for many purposes to measure aggregate energy demand or aggregate energy demand elasticities as close to the point of consumption as possible.¹⁴ This suggests measurement of elasticities at the retail level. However, it was felt that a standardized comparison at the retail level would be impractical because there are many different retail products sold to many consumers in many localities at many different prices.

In this study, energy is measured at the primary level and at the secondary level.

Lack of appropriately disaggregated data at the retail level has also prompted many of the modelers to look elsewhere in the system for a point of measurement where the aggregation assumptions can be satisfied. The U.S. Bureau of Mines has historically referred to energy measured directly before electricity generation and other conversion losses as gross energy inputs and energy measured directly after these losses as net energy inputs. In this study, these quantities are referred to as primary and secondary energy, respectively.

For a single fuel, the relationship between elasticities measured at different points is straightforward.

In general, it is difficult to separate problems of aggregation from problems associated with point of measurement. However, for models which consider only one fuel, the importance of the point of measurement problem can be easily demonstrated. For example, the Sweeney Auto model considers only automobile gasoline use and, therefore, problems of aggregation do not appear in presenting the results of the model. Sweeney, of course, used data aggregated from individual gasoline sales. Calculation of retail price elasticity and secondary price elasticity are straightforward; calculation of primary elasticity requires a modeling of cost and quantity changes associated with refinery operations.

In this case two types of markups are common.

For the simple case in which there are price markups and energy conversion losses from point to point in the energy production/consumption chain, differences in elasticities are easy to calculate. Two types of markups between levels are common. A

proportional markup multiplies the lower level price by some constant greater than unity, while an additive markup adds some fixed cost to the price. The proportional markup guarantees that the same percentage changes in prices and quantities occur at each level in the system and, therefore, elasticities are the same at each point of measurement. For additive markups, an increase in price at one level produces a different percentage change in price at another level. This results in different elasticities at different points of measurement.

With additive markups, retail elasticities exceed secondary elasticities, which exceed primary elasticities.

Suppose prices at the retail, secondary, and primary levels are denoted by PR, PS, and PP, respectively, and that there are additive markups, TR and TS, between the secondary and retail levels and between the primary and secondary levels, respectively. The secondary elasticity will be smaller than the retail elasticity by a factor of $(PR - TR)/PR$, while primary elasticity will be smaller than secondary elasticity by a factor of $(PS - TS)/PS$. The elasticity at a point in the supply chain, e.g., primary energy, will be smaller than the elasticity at a point farther downstream, e.g., retail energy, whenever there are additive markups between levels.

As an example, elasticities are calculated at three levels for the Sweeney Auto model. At the retail level, the elasticity is 0.76, while at the secondary and primary levels the corresponding elasticities are 0.46 and 0.40, respectively.

Similar calculations have been performed for the aggregate of all energy in the economy, under an assumption that all price increases between the secondary and retail levels can be modeled as additive markups. Figure 4 illustrates the relationship between the secondary and retail elasticities, assuming additive markups and normalizing the elasticity at the retail level to unity.¹⁵ Under these assumptions, the ratio between the two elasticities increases sharply as energy price increases.

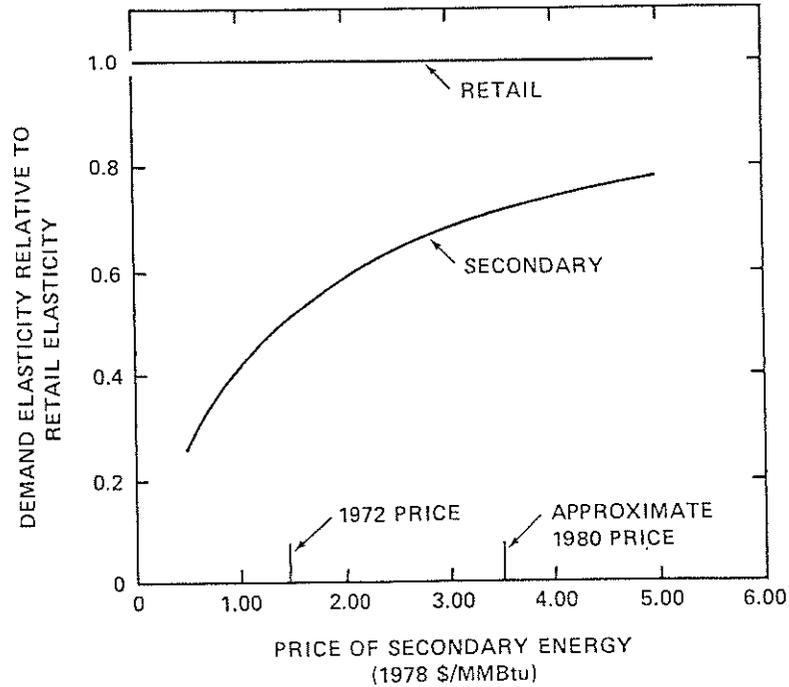


Figure 4 Ratio of Retail and Secondary Elasticities as a Function of Secondary Energy Price

A general method for translating elasticities from point to point is proposed.

Nissen, in Volume 2 Chapter 5, has proposed a general methodology for translating elasticities from point to point in the presence of interfuel competition. This method promises to provide a comprehensive approach for estimating aggregate functional approximations of detailed models.

Aggregate primary and secondary elasticities are computed for each model.

A majority of researchers report total energy before conversion losses, and this point of measurement is employed in many discussions of aggregate energy demand. Therefore, the study was designed to produce estimates of primary elasticities implicit in the models. However, since enough data were available to also estimate secondary energy price elasticities implicit in the models, the working group calculated and reported elasticities at both points of measurement.

Dynamics

Dynamic responses of the models to price increases are not examined.

In general, since the capital stock of energy-using equipment adjusts only slowly, short-run elasticities (one to five years) may be expected to be considerably smaller than long-run elasticities. Furthermore, calculated elasticities may depend upon the timing of price changes. The working group calculated 15-, 25-, and 35-year aggregate elasticities in response to price changes initiated in 1975. Thus, while the estimates are not precisely long-run equilibrium elasticities, the 25- and 35-year estimates closely approximate long-run elasticities. The experiment does not examine the dynamics of the models, although several models explicitly account for delays in consumer responses to changes in energy prices.

Long-run elasticities greatly exceed short-run elasticities.

Slow adjustment creates another empirical problem. When data used for econometric testing are derived from a short time period, only short-run elasticities can be easily observed. Therefore, elasticities estimated using only a short time series of data, for example, only post-1973 data, are heavily dependent upon assumptions about the rate of adjustment of the capital stock. The timing of consumer responses and the analysis of post-1973 data are discussed at length in Volume 2 Chapters 12 and 13.

Characterizing Uncertainty

It is desirable to examine the uncertainty associated with elasticity estimates;

Assumptions about price responsiveness are central to conclusions obtained in energy policy studies. Consequently, it is desirable to characterize the uncertainty associated with aggregate elasticity estimates. This is especially true since error costs may be asymmetric and highly nonlinear. The costs of taking actions based upon overestimates of energy demand elasticities may be very different from those based upon underestimates.

however, this goal could not be achieved.

Unfortunately, the theory and data are not available to develop a satisfactory description of the uncertainty associated with the aggregate elasticity estimates. The lack of a formal description of the processes by which the energy system structure can change may be the most important source of error in elasticity

estimates. The working group could not meet the data and computational requirements for characterizing uncertainty even for the conceptually simple problem of measuring the propagation of parameter error in the models. This troublesome problem, which is discussed in Volume 2 Chapter 11, remains as a caution to model users and a challenge to model developers.

OVERVIEW OF THE MODELS

Sixteen models were analyzed.

Sixteen models were included in this study, as shown in Table 2. The models are described in detail in Volume 2 Chapter 3. While the models emphasize different aspects of energy demand, they overlap in their estimation of the relationships between energy demands and energy prices. These models are representative of the spectrum of available analysis tools and share many important features.

The models vary in scope.

The models vary in scope, including sectoral models, energy system models, and energy-economy models.¹⁶ The energy system models represent the entire energy system, while the sectoral models focus on specific sectors of the energy system, thus resembling components of the energy system models. The energy-economy models explicitly represent the influence of changes in the energy system upon the rest of the economy, while the energy system models do not.

The energy-economy models include energy-economy interactions.

The energy-economy models include consideration of energy demand within a general equilibrium framework representing the economy. These models typically use an economic growth model to integrate (1) an interindustry input-output description of the economy's production sector, (2) a detailed process description of the energy sector, and (3) a consumer demand module. However, the models differ substantially in level of aggregation, representation of substitution possibilities, and representation of energy supply and demand dynamics. The energy-economy models included in the study are (1) BESOM/H-J, a simplified version of the Brookhaven system/Hudson-Jorgenson, (2) ETA-MACRO, and (3) Parikh WEM. All of these models are nationally aggregated.

Energy system models represent all energy demands.

The energy system models represent all energy demands but not interactions between the energy sector and the rest of the economy. These models also differ substantially in level of aggregation, substitution possibilities, and representations of energy supply and demand dynamics. The energy system models included in the study are (1) Baughman-Joskow, (2) EPM, (3) FOSSIL1, (4) Griffin OECD, (5) MEFS, and (6) Pindyck.^{17,18}

Sectoral models include detailed representations of specific energy-consuming sectors.

The sectoral models address energy use in specific demand sectors. Typically, these models have little detail on energy supply, and they do not consider energy conversion processes or energy-economy feedbacks. On the other hand, concentration on one demand sector allows a more detailed modeling of various energy uses. The study included seven sectoral models: (1) BECOM, (2) FEA-Faucett, (3) Hirst Residential, (4) ISTUM, (5) Jackson Commercial, (6) Sweeney Auto, and (7) Wharton MOVE.

The models differ systematically in data and accounting systems.

The models systematically differ in the data and accounting systems used. The energy-economy models typically utilize U.S. Bureau of Economic Analysis (BEA) industrial classifications. This allows commercial energy demands and transportation demands, except gasoline for private automobiles, to be treated in an interindustry input-output framework. In the energy system models, demands are typically disaggregated by U.S. Bureau of Mines (BOM) consuming sectors: residential, transportation, commercial, and industrial.

The models focus on different system elements contributing to energy demand flexibility.

Each model includes some mechanism for projecting future energy demands, and each examines some aspects of the role of prices in determining demands. Total demand for energy can adjust in many ways, and the models focus on different system elements that contribute to the flexibility in energy demand, fixing some quantities while determining others. At one extreme, the BECOM and ISTUM models hold constant all demands for energy services, solving for the specific equipment and fuels required to provide those energy services at the lowest cost. At the other extreme, the Griffin OECD and Pindyck models implicitly allow all system adjustments to be captured in their parameter estimation.

Some models explicitly include substitution processes; others leave these processes implicit.

Some models, such as BECOM, BESOM/H-J, or Hirst Residential, explicitly identify the precise channels through which the substitution occurs, using a detailed process representation or an aggregate production function representation of labor, capital, energy, and materials substitution. Other models, such as Baughman-Joskow, Griffin OECD, and Pindyck, leave substitution processes implicit.

The responsiveness of demand includes inter-fuel and factor substitution.

The responsiveness of demand to price changes can be thought of as being composed of two components: interfuel substitution and factor substitution. Inclusion of interfuel substitution permits examination of those interactions where the choice of one form of energy versus another is important. Inclusion of factor substitution permits representation of switches from energy to other factors of production. The degree of interfuel and factor substitutions represented varies significantly among the models employed in the study.

The degree of product and geographic aggregation varies significantly among the models.

Also varying among the models is the degree of product and spatial aggregation. Geographic aggregation is important because many economic decisions can vary between regions, and the ability to transport energy between regions may be limited in some cases. The level of product aggregation can be important to the extent that alternative energy products are not perfect substitutes. The significance of both issues is that the aggregation level implicitly defines some of the substitution possibilities included in the models. Specifically, commodities within a particular product or regional aggregate are implicitly considered to be perfect substitutes or perfect complements, i.e., used only in fixed proportions, for each other.

Representation of energy conversion activities influences a model's aggregate primary elasticity.

Because the study required specification of exogenous price trajectories for primary energy fuels, the resource supply dynamics built into the models are irrelevant for comparison of demand behavior. However, representations of energy conversion activities are important for determining aggregate elasticity of demand for primary energy. Three energy conversion sectors are typically included in the models: (1) an electric utility sector,

(2) an oil refining sector, and (3) a coal synthetics conversion sector. These are represented quite differently among the various models.

Some models represent the dynamics of the demand response; others are static.

Slow adjustment of capital stock, location patterns, and behavioral choices typify the energy demand response to changes in economic conditions. Energy models can be either static or dynamic. The static models, such as BESOM/H-J and Pindyck, do not explicitly incorporate either foresight or slow adjustment processes. In contrast, dynamic models like ETA-MACRO incorporate temporal considerations within a multiperiod framework.

Some dynamic models assume perfect foresight; others assume myopic behavior.

Two attributes may be used to describe the differences across dynamic models: treatment of expectations and speed of adjustment. Expectations may be myopic, with current decisions determined entirely by current and past conditions, or clairvoyant, with current decisions based upon complete knowledge of all past, present, and future prices. The statistical models implicitly embody myopic expectations, while intertemporal optimization models, such as BECOM, assume clairvoyant behavior. A model might permit instantaneous adjustment in variables resulting from exogenous shocks or the adjustment may be gradual.

In all the dynamic models, a key element is the treatment of adjustments in the stock of capital goods. Some models, such as FEA-Faucett, Hirst Residential, and Wharton MOVE, treat these capital adjustment processes explicitly, while others, such as Baughman-Joskow or Griffin OECD, leave these processes implicit in the model equations and parameters.

Statistical, engineering, and judgmental parameter estimation approaches are employed.

Besides differing in sectoral coverage, treatment of the relationship between the energy sector and the rest of the economy, and in several important structural characteristics, the models differ fundamentally in approaches to parameter measurement. The model developers employed one or more of three basic approaches:

- (1) statistical estimation of fuel and/or sector price response,
- (2) detailed engineering specifications of alternative energy-using technologies, and
- (3) judgmental estimation of fuel and/or

sector price response. Table 3 indicates the principal methods used for parameter estimation. Some models include a combination of approaches to parameter estimation. Of these, BESOM/H-J and ETA-MACRO are classified according to the parameter estimation methods used to develop the demand representation of the model. However, such a classification was not possible for the Hirst Residential and Jackson Commercial models since the statistical and engineering approaches were intertwined in these models. The comparison of estimation methods can be found in Volume 2 Chapter 3.

THE EXPERIMENTAL DESIGN

Primary energy fuel prices were varied; other assumptions were standardized across scenarios and models.

Except for primary energy fuel prices, which were varied during the experiment, all energy sector assumptions were those used by the Modeling Resource Group (MRG) of the Committee on Nuclear and Alternative Energy Systems (CONAES) study.¹⁹ The constant dollar price levels of oil and gas, coal, and nuclear fuel for

Table 3
PARAMETER ESTIMATION APPROACHES

	Statistical	Engineering	Judgmental
Energy-Economy Models	BESOM/H-J		ETA-MACRO Parikh WEM
Energy System Models	Baughman-Joskow ^a Griffin OECD MEFS Pindyck		EPM FOSSIL1
Sectoral Models	FEA-Faucett Sweeney Auto Wharton MOVE ^b Hirst Residential ^c Jackson Commercial ^c	BECOM ISTUM	

^aExcludes the transportation sector and industrial feedstocks

^bOnly results from the automobile gasoline demand component were reported to the EMF.

^cCombines both the statistical and engineering approach

the Reference price case were chosen to increase gradually over time. Oil and gas were assumed to cost \$2.00 per million Btu in 1975 and to increase 2 percent per year in real terms through 2010;²⁰ coal and nuclear fuel were assumed to cost \$0.75 and \$0.40 per million Btu in 1975, respectively, and to increase 1 percent per year through 2010. The reference price levels are not especially important: the elasticities are calculated based on the changes in prices from those levels and the resulting changes in quantities.

Changes in aggregate price level and individual fuel prices were considered.

The alternative cases explored changes in the composition of the aggregate price around the reference price levels as well as changes in the aggregate price level (Volume 2 Chapter 2). The primary energy input prices were increased or decreased 25 percent for all years, yielding three price levels for each primary energy input. The price levels were varied from their reference levels individually and collectively, defining the nine primary energy price cases shown in Table 4.

Each price case was run for each model. The resulting demand projections by fuel and sector were reported to the working group by all modeling teams except for Wharton Econometric Forecasting Associates, whose representative reported results only from their automobile gasoline demand model (MOVE).²¹

A constant elasticity demand function was estimated for each model for several years.

The EMF staff used the reported data to calculate price and quantity indexes for each model in each price case for 1990, 2000, and 2010. The Reference case prices and demands for the particular year of interest were used as weights in the indexes. A simple constant elasticity aggregate energy demand function was statistically fit to the aggregate data for all cases available from a given model in a particular year.²² Thus, a single best aggregate elasticity estimate was obtained for each model and each year.

Table 4

PRIMARY ENERGY PRICE CASES

Case	Price Level		
	Oil & Gas	Coal	Other
1. Reference	Reference	Reference	Reference
2.	High	Reference	Reference
3.	Reference	High	Reference
4.	Reference	Reference	High
5.	High	High	High
6.	Low	Reference	Reference
7.	Reference	Low	Reference
8.	Reference	Reference	Low
9.	Low	Low	Low

CONCLUSIONS

The magnitude of the demand elasticity depends on a number of factors.

Contrary to popular usage, the energy demand elasticity cannot even be defined consistently without explicit specification of several factors. The point of measurement, method of aggregation, price change composition, time frame, taxes, and regulations assumed can significantly affect the calculated value of the aggregate elasticity. Even if these factors are standardized, differences in parameter estimation approaches and structural characteristics lead to a range of elasticity estimates.

The Point of Measurement

Results showed no consistent relationship between secondary and primary elasticity estimates.

The results in Table 5 show no consistent relationship between primary and secondary aggregate elasticity estimates generated within the study. The difficulty seems to reside chiefly with primary elasticity estimates. In calculating primary elasticities for sectoral models, a somewhat arbitrary exogenous mix of fuels for electricity generation was assumed. In addition, aggregation problems seemed to be more severe when primary energy consumption estimates rather than secondary estimates were utilized.

Table 5
COMPARISON OF 25-YEAR PRIMARY AND SECONDARY
ELASTICITY ESTIMATES
(Paasche Index)

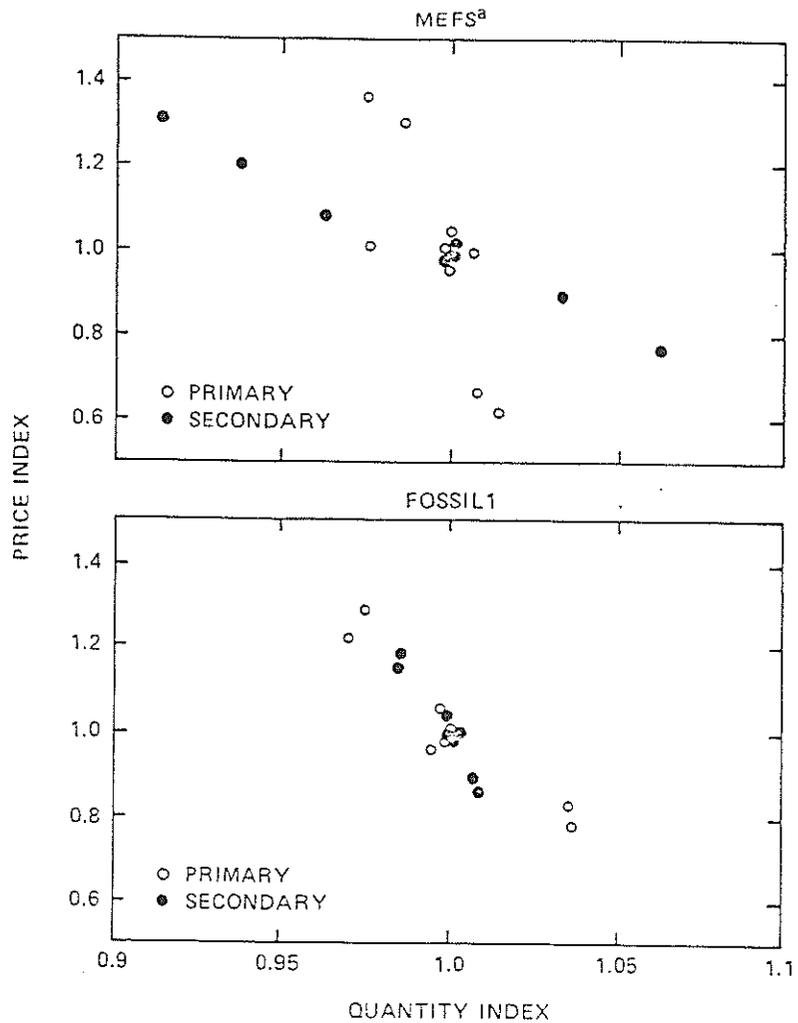
Model	Demand Sector	Elasticity of Demand	
		Primary	Secondary
Baughman-Joskow	Total	0.49	0.61
BECOM ^a	Residential/ Commercial	--	0.51
BESOM/H-J	Total	0.48	0.42
EPM	Total	0.79	0.57
ETA-MACRO	Total	0.30	0.18
FEA-Faucett ^{a,b}	Auto	0.13	0.15
FOSSILL	Total	0.11	0.08
FOSSILL Conservation	Total	0.17	0.16
Griffin OECD	Total	0.45	0.55
Hirst Residential ^b	Residential	0.24	0.44
ISTUM	Industrial	--	0.24
Jackson Commercial ^b	Commercial	0.17	0.37
MEFS ^{a,b}	Total	0.04	0.31
Parikh WEM	Total	0.11	0.10
Pindyck ^b	Total	0.44	0.70
Sweeney Auto ^{a,b}	Auto	0.40	0.46
Wharton MOVE ^a	Auto	0.19	0.21

^a15-year estimates reported

^bNo electricity generation sector

Primary elasticity estimates were too unreliable; the study focused on secondary elasticities.

Figure 5 displays primary and secondary price and quantity indexes generated for the various scenarios for two models. For the MEFS model, the aggregation problem is signaled by the irregular scatter of aggregate primary energy price and quantity observations. While both the primary and secondary data are scattered over a region, it is easier to estimate a functional relationship between secondary energy price and quantity. The differences were not nearly as striking for the FOSSILL model. However,



^a15-year estimates only

Figure 5 25-Year Total Demand Primary and Secondary Energy Price Responses for the MEFS and FOSSIL1 Models

decomposition results, discussed at a later point, confirmed the judgment that primary energy elasticities were too undependable. Therefore, the working group decided to concentrate on the secondary energy elasticities.

The Choice of Index

Except for the Btu-weighted, elasticity estimates were not sensitive to choice of index.

Secondary aggregate elasticity estimates were not sensitive to the choice of Paasche, Laspeyres, Ideal, or Tornquist indexes. But for some models the use of a Btu-weighted index led to different calculated elasticities, as shown in Table 6. These results suggest the importance of specifying the class of price index used whenever aggregate elasticities are reported. Because the Btu-weighted index is theoretically less attractive, the Paasche index is used in reporting results in the present report.

Table 6

COMPARISON OF 25-YEAR SECONDARY DEMAND ELASTICITY ESTIMATES
BASED ON SELECTED INDEXES^a

Model	Index			
	Tornquist	Paasche	Laspeyres	Btu-weighted
Baughman-Joskow	0.61	0.61	0.61	0.59
BECOM	0.54	0.51	0.57	1.00
BESOM/H-J	0.43	0.42	0.44	0.46
EPM	0.57	0.57	0.57	0.59
ETA-MACRO	0.19	0.18	0.20	0.35
FEA-Faucett ^b	0.15	0.15	0.15	0.15
FOSSILL	0.08	0.08	0.08	0.14
FOSSILL Conservation	0.16	0.16	0.16	0.23
Griffin OECD	0.56	0.55	0.57	0.68
Hirst Residential	0.45	0.44	0.45	0.47
ISTUM	0.24	0.24	0.24	0.01
Jackson Commercial	0.38	0.37	0.38	0.33
MEFS ^b	0.31	0.31	0.32	0.33
Parikh WEM	0.09	0.10	0.09	0.10
Pindyck	0.71	0.70	0.71	0.66
Sweeney Auto ^b	0.46	0.46	0.46	0.46
Wharton MOVE ^b	0.21	0.21	0.21	0.21

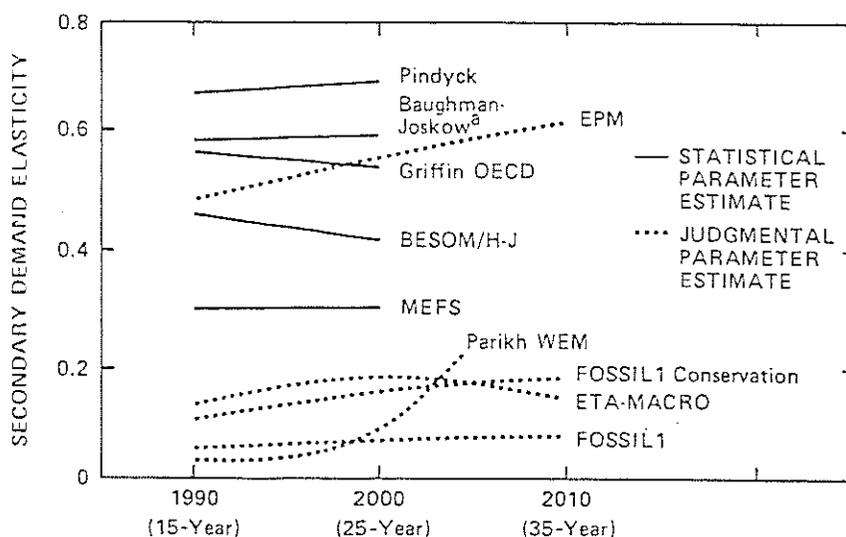
^a Same demand sectors as reported in Table 5

^b 15-year estimates reported

The Method of Parameter Measurement

The comprehensive statistically estimated models produced higher elasticity estimates than did those models with judgmental parameter estimates.

The aggregate secondary demand elasticity estimates are shown in Figure 6. The more comprehensive models, covering all energy-using sectors, incorporating the full range of potential substitutions, and directly utilizing historical data to estimate statistically the demand parameters, were generally characterized by higher implicit long-run aggregate secondary demand elasticities than were the other models. The statistically estimated models are represented with solid lines in Figure 6 and include Baughman-Joskow (0.6), BESOM/H-J (0.4), Griffin OECD (0.5), MEFS (0.3), and Pindyck (0.7). The models that consider all consuming sectors but employ judgmental parameter estimates generally exhibit lower elasticities. These models are represented with broken lines in Figure 6 and include EPM (0.6), ETA-MACRO (0.2), FOSSIL1 (0.1), FOSSIL1 Conservation (0.2), and Parikh WEM (0.1).²³



Note: The Paasche index was used to calculate these estimates.

^a Does not include transportation demands

Figure 6 Aggregate Total Demand Elasticity Estimates

Statistical models could be biased in either direction.

The statistical approach is based on the analysis of historical data and consequently presumes that technology accommodating new combinations of productive factors will be available. Thus, these methods may tend to overestimate or underestimate the flexibility in the system, depending on whether the technological response to changing prices turns out to be greater or less than the historical response.

However, the statistically estimated models produced consistently high elasticities,

Table 7 presents 25-year elasticities by sector for all models included in the study. These numerical results demonstrate consistently high elasticities among the statistically estimated models. If these models most correctly describe the future behavior of energy demand, energy growth can be substantially decoupled from economic growth, energy conservation programs can effectively lower energy consumption, and energy supply development programs are less critically needed.

while judgmental models demonstrated lower elasticities.

The judgmental models also show a surprising degree of consistency in projected responses to higher energy prices, exhibiting relatively low demand elasticities. If these models most correctly describe the energy system, energy growth will be tightly linked to economic growth, energy conservation programs cannot be expected to greatly lower energy consumption, and supply development programs are more critically needed.

A consensus on the most likely elasticity was not achieved.

After much debate, the working group was unable to reach a consensus as to which class of models most accurately describes the world. Aggregate demand elasticity estimates from the various models are provided to sharply delineate the range of disagreement on the probable values of this critical summary statistic.

Differences in Model Structure

Structural characteristics represented in a model can influence its elasticity.

Structural characteristics represented in a model can also influence the calculated elasticity. Since there are many ways total energy demand can change in response to changing incentives, failure to implicitly or explicitly represent each of the basic adjustment mechanisms will bias elasticities downward.

Table 7

25-YEAR SECONDARY DEMAND
ELASTICITIES BY SECTORS
(Paasche Index)

Sector	Statistical	Engineering	Judgmental
Residential	Hirst Residential ^a	0.4	
	Griffin OECD	0.9	BECOM 0.6
	MEFS	0.5	
	Pindyck	1.0	
Residential/ Commercial	Baughman- Joskow	0.8	BECOM 0.5 EPM 0.5
	BESOM/H-J	0.7	
	MEFS	0.5	
Commercial	MEFS	0.5	BECOM 0.3
	Jackson Commercial ^a		0.4
Commercial/ Industrial	Griffin OECD	0.3	
	Pindyck	0.7	
Industrial	Baughman- Joskow	0.4	ISTUM 0.2 EPM 0.7
	BESOM/H-J	0.5	
	MEFS	0.2	
Transporta- tion ^b	BESOM/H-J	0.2	EPM 0.4
	FEA-Faucett	0.1	
	Griffin OECD	0.5	
	MEFS	0.3	
	Pindyck	0.5	
	Sweeney Auto	0.5	
	Wharton MOVE	0.2	
All Sectors	Baughman- Joskow ^c	0.6	EPM 0.6
	BESOM/H-J	0.4	ETA-MACRO 0.2
	Griffin OECD	0.5	FOSSILL 0.1
	MEFS	0.3	FOSSILL ^d 0.2
	Pindyck	0.7	Parikh WEM 0.1

^a Combines both the engineering and statistical approach

^b The FEA-Faucett, Sweeney, and Wharton MOVE results are for automobile gasoline only. These are 15-year elasticities. All runs exclude the new car fuel efficiency standards.

^c Excludes the transportation sector

^d FOSSILL Conservation

Models representing components of energy demand as independent of price bias elasticity estimates downward.

Several of the sectoral energy models represent components of energy demand as independent of price, thereby biasing downward the calculated aggregate elasticity. For example, BECOM and ISTUM assume end-use service demands to be independent of price. This constraint within the model ignores the possibility of selecting alternative processes for the production of a given commodity; it even precludes the possibility of modifying thermostat settings in response to higher fuel prices. This modeling approach, therefore, biases elasticity estimates downward.

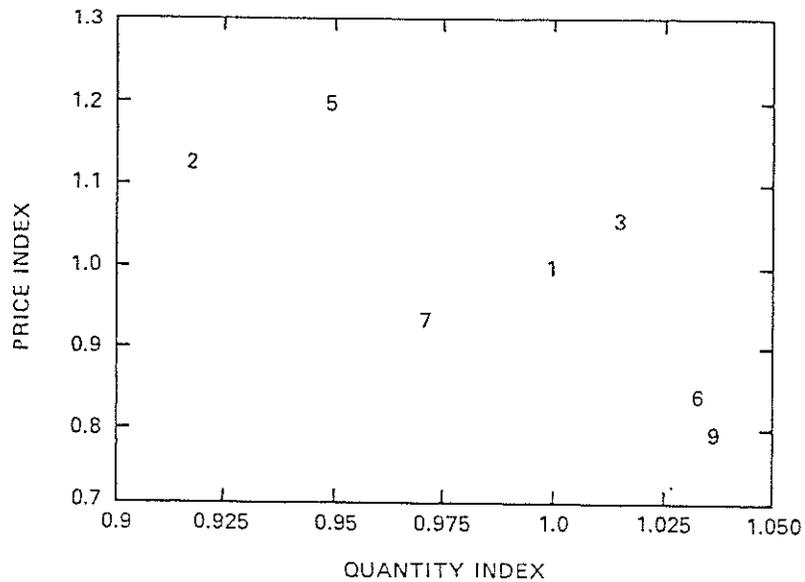
Elasticity estimates from sectoral models were lower than estimates from comprehensive models.

The range of estimates from the sectoral models, as shown in Table 7, was from 0.1 for FEA-Faucett to 0.6 for BECOM, and included 0.4 for Hirst Residential, 0.2 for ISTUM, 0.4 for Jackson Commercial, 0.5 for Sweeney Auto, and 0.2 for Wharton MOVE. In general, sectoral models are characterized by lower elasticities than those characterizing corresponding sectors of the more comprehensive models. This difference may occur partially because many sectoral models use engineering process data including a limited range of technological options. The effects of differences in model structure on the elasticity estimates are discussed in more depth by Griffin and Wood in Volume 2 Chapter 8.

The Composition of Price Change

Some model results were very sensitive to the price change composition; for these models, an aggregate elasticity can be misleading.

The results from many models were sensitive to the specific composition of price changes. For these models, an aggregate analysis may be inadequate or misleading. For example, Figure 7 shows price and quantity indexes generated by applying the ISTUM model to seven of the price cases. If the secondary energy price and quantity indexes were available only for cases 1, 3, and 7, the ISTUM aggregate elasticity estimate would be negative: aggregate price increases would be expected to lead to aggregate demand increases, not decreases! This anomalous result occurs primarily because oil and gas price and demand play crucial roles in aggregate index computation and because oil and gas prices remain unchanged over these three scenarios. Conversely, if only cases 1, 5, and 9 or only cases 1, 2, and 6 were available, positive elasticities would be calculated, although the magnitudes would differ in these two situations.



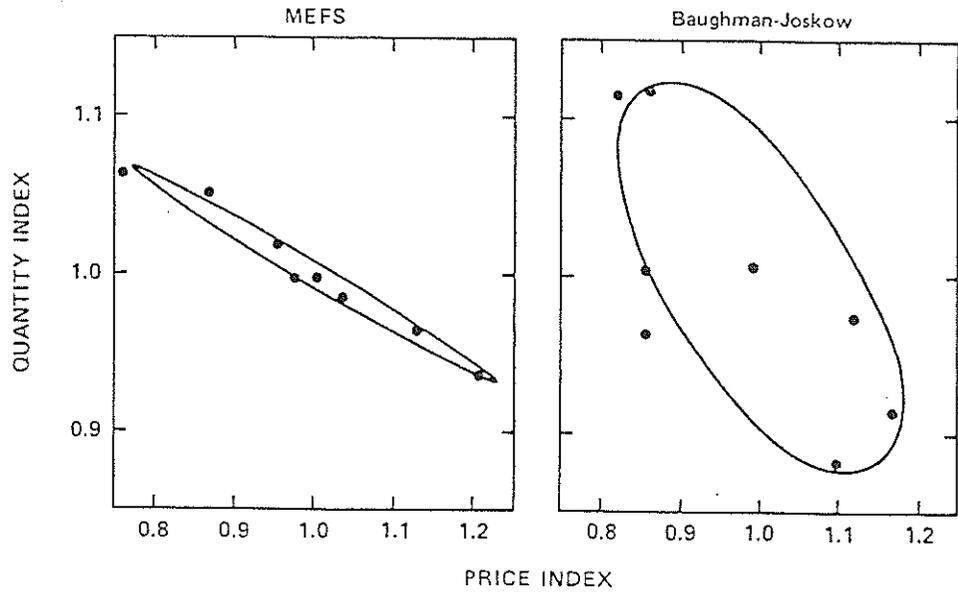
Note: The numbers refer to price cases. The Paasche index was used to calculate these estimates.

Figure 7 25-Year Industrial Secondary Energy Index Values for the ISTUM Model

A single-valued demand function for an aggregated class of commodities may not exist, as has been illustrated above. In this case, the notion of an aggregate demand function must be replaced with the notion of a demand region: a set of price and quantity index combinations which could occur in response to price changes of fixed magnitude but varying directions. The decomposition approach provides an approximate description of the shape of such a demand region and includes a method for fitting the region to data generated by the various models.

The decomposition results from two models are contrasted.

Figure 8 illustrates the decomposition results for the MEFS and Baughman-Joskow models. The ellipse in each graph provides an estimate of the demand region outer limits generated in response to price changes of unit magnitude but varying direction. Each graph includes individual observations from the models, scaled to unit magnitude price changes. Aggregate elasticities from the MEFS model are much less sensitive to the direction of the



Note: The Paasche index was used to calculate these estimates.

Figure 8 Comparison of 25-Year Secondary Energy Decomposition Results from the MEFS and Baughman-Joskow Models

price change than are those from the Baughman-Joskow model. Consequently, greater care must be exercised in calculating and using aggregate elasticity estimates from the Baughman-Joskow model.

Decomposition parameter estimates for all models are presented.

Table 8 presents results obtained by applying the decomposition technique to those models that ran sufficient numbers of scenarios. The limited number of independent observations from the other models precluded the use of this technique. For each index, three numbers characterize the demand region approximation for each model:

- σ , the average elasticity, represents the elasticity averaged over all possible price directions;
- τ , the directional elasticity, represents the demand region width (the maximum quantity index change occurring at zero price index change, divided by the maximum price index change); and

Table 8
25-YEAR SECONDARY FUELS DECOMPOSITION RESULTS
(Paasche Index)

Model	Sector	Average	Directional	Shape
		Elasticity σ	Elasticity τ	Factor ν
Baughman-Joskow	Total	0.46	0.53	1.14
BECOM ^a	Residential/ Commercial	-4.08	-3.86	0.94
BESOM/H-J	Total	0.52	0.42	0.80
EPM	Total	0.45	3.22	7.17
ETA-MACRO	Total	0.22	0.05	0.25
FOSSIL1	Total	0.07	0.05	0.68
FOSSIL1 Conservation	Total	0.15	0.06	0.36
Griffin OECD	Total	0.67	1.58	2.34
Hirst Residential ^{a,b}	Residential	0.31	0.24	0.78
ISTUM ^b	Industrial	-3.74	7.76	-2.07
Jackson Commercial ^{a,b}	Commercial	0.32	0.09	0.28
MEFS	Total	0.29	0.03	0.11
Parikh WEM ^b	Total	0.15	0.92	6.23
Pindyck	Total	0.68	0.04	0.06

^aLess than three fuels were reported

^bLess than eight scenarios were reported

- ν , the shape factor, represents the width relative to the average elasticity.

These parameters are described more fully in Volume 2 Chapter 9.

The shape parameter summarizes sensitivity to price change composition. Low shape parameter values imply the aggregate elasticity is a good summary descriptor.

The shape factor (ν) can be used to indicate the range of price change directions for which the average demand elasticity (σ) closely approximates a model's behavior. Large values of the shape factor imply that the actual elasticity is highly dependent upon the direction of price change while small values imply a relative insensitivity to direction. For example, if all directions of price change are viewed as possible, absolute values of the shape factor less than 0.4 imply actual model elasticity is within plus-or-minus 50 percent of the average elasticity for 71 percent

of all possible directions and within 20 percent for 55 percent of directions. Absolute values of the shape factor greater than 2 imply the actual model elasticity differs from the average elasticity by more than plus-or-minus 50 percent for 69 percent of the directions and by more than 100 percent for 53 percent of the directions.

Using this criterion, the average secondary elasticity provides a poor descriptor of the Baughman-Joskow, EPM, Griffin OECD, and Parikh WEM models and a relatively weak descriptor of the BECOM and FOSSIL1 models. For these models, the aggregate secondary demand elasticity is highly sensitive to directions of price change. Conversely, the average secondary elasticity provides a good summary descriptor of the ETA-MACRO, Jackson Commercial, MEFS, and Pindyck models.

For most models, the aggregate secondary elasticity provides a better descriptor than aggregate primary elasticity.

As shown in Table 9, the average primary elasticity provides a good summary descriptor for fewer models, BESOM/H-J and Pindyck, and a poor descriptor for many models. For many of the models, the shape factor is larger when estimates are based upon primary data rather than secondary data. This confirms the judgment that the aggregate elasticity of primary energy is less reliable as a model descriptor than is the aggregate elasticity of secondary energy.

Response Dynamics

Many models include rudimentary descriptions of adjustment processes.

Although energy demands can be expected to change gradually in response to price changes, many models include only rudimentary descriptions of the adjustment processes and thus cast little light on the response dynamics. Yet, energy policy and planning debates generally require information not only about the 25-year responses to actions taken now but also about responses occurring over the first weeks, months, or years after the price change. Failure of modelers to examine the short-run demand responses to price changes in conjunction with the long-run responses or, worse yet, a failure to properly differentiate among the various time horizons will tend to seriously limit model usefulness.

Table 9

25-YEAR PRIMARY FUELS DECOMPOSITION RESULTS
(Paasche Index)

Model	Sector	Average	Directional	Shape
		Elasticity σ	Elasticity τ	Factor ν
Baughman-Joskow	Total	-0.95	1.15	-1.21
BESOM/H-J	Total	0.57	0.17	0.29
EPM ^a	Total	-0.56	1.23	-2.22
ETA-MACRO	Total	0.57	0.95	1.66
FOSSIL1	Total	0.03	0.13	4.12
FOSSIL1 Conservation	Total	0.07	0.15	2.15
Griffin OECD	Total	0.32	0.37	1.15
Hirst Residential ^a	Residential	0.23	-0.05	-0.21
Jackson Commercial ^a	Commercial	0.17	-0.02	-0.14
MEFS	Total	0.07	0.24	3.45
Parikh WEM ^a	Total	-6.48	26.70	-4.12
Pindyck	Total	0.47	0.03	0.07
Wharton MOVE	Total	0.27	0.47	1.75

^aLess than eight price cases were reported.

25-year elasticities were used as long-run equilibrium values.

The model comparisons performed in the present study did not allow examination of the adjustment processes to higher prices inherent in the models. Nor were long-run equilibrium elasticities directly estimated. Rather, 25-year elasticities were taken as estimates of the long-run equilibrium values. Since Fromholzer and Lau (Volume 2 Chapter 11) have shown that the particular price paths employed in the study probably lead to only a very small--less than 10 percent--divergence between long-run equilibrium elasticity estimates and 25-year elasticities, the failure to directly estimate long-run equilibrium values should not be of great consequence.

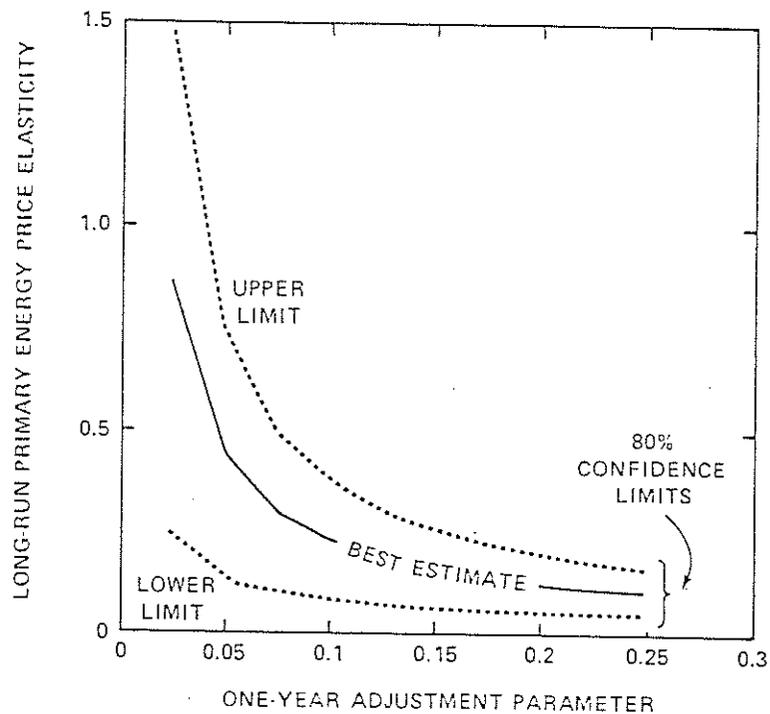
The post-1973 experience could be consistent with the entire range of primary elasticities.

Only Manne and Wilson (Volume 2 Chapter 12) and Hogan (Volume 2 Chapter 13) attempted to directly calculate the aggregate elasticity from historical data rather than developing disaggregated models. These analyses have value as pedagogical devices and as mechanisms for performing several simple, but important,

consistency checks. Incorporating recent historical data within the framework of a dynamic adjustment model allows comparison of recent historical trends with long-run aggregate elasticity estimates obtained from the models included in the present study.

In a particular year, the response of demand to higher prices depends on the long-run elasticity and the lag parameter.

For example, the solid line in Figure 9 plots the mean primary energy demand elasticity estimates from the Manne-Wilson analysis as a function of the lag parameter. The lag parameter represents the ratio of the one-year elasticity to the long-run equilibrium elasticity. It can be very roughly interpreted as the fraction of energy-consuming capital stock newly installed each year. Since the fraction of capital stock newly installed each year is normally small--certainly less than 0.25, and probably less than 0.1--the one-year adjustment parameter can be expected to be correspondingly low. Thus, the Manne-Wilson analysis, which incorporates data from the post-1973 experience, indicates that the primary energy consumption changes actually experienced through 1978 could be consistent with the entire range of estimated long-run elasticities implicit in any of the models participating in



Note: These are direct estimates from 1950-1978 aggregate data.

Figure 9 Dependence of Long-Run Elasticity Estimates on Assumed One-Year Adjustment Parameter

the experiment. Taken alone, the post-embargo primary energy data do not provide sufficient evidence to reject either higher elasticity estimates from the statistical models or lower elasticity estimates from the other models.

Taxes and Regulations

Taxes and regulations can alter the demand elasticity.

Taxes and regulations can also significantly influence the demand elasticities. For example, gasoline taxes lead to an additive markup on gasoline price, causing the retail demand elasticity to differ from the secondary elasticity. The larger the gasoline tax, the greater the wedge between these elasticities. Thus, increases in gasoline taxes can be expected to reduce the secondary elasticity if the retail elasticity is left unchanged.

Fuel-use efficiency standards tend to reduce demand elasticities while reducing energy consumption.

Regulations which mandate the characteristics of energy-consuming equipment tend to reduce the demand elasticity while presumably reducing energy consumption. For example, the imposition under the Energy Policy and Conservation Act (EPCA) of binding corporate average fuel efficiency (CAFE) standards on automobile manufacturers implies that, over the range of prices for which the standards are binding, the average new car fuel efficiency will cease to be greatly dependent upon gasoline price. The penalties motivate manufacturers to just meet the standards, but provide no motivation for exceeding them. The standards preempt the consumers' shifts toward more efficient automobiles as gasoline prices increase. Therefore, in the presence of binding standards, automobile fleet characteristics will depend less upon gasoline price and the demand elasticity for gasoline will decrease. As shown in Table 10, this phenomenon appears striking in results from the Sweeney Auto model and less dramatic in results from the FEA-Faucett and Wharton MOVE models.

This effect is stronger in some models than in others.

The secondary elasticity for the Sweeney Auto model is slightly less than 0.5 without the CAFE standards and slightly less than 0.2 with these standards. The Wharton MOVE and FEA-Faucett model elasticities are also somewhat less in the presence of the standards.

Table 10

15-YEAR SECONDARY ELASTICITY ESTIMATES WITH AND WITHOUT CAFE^a STANDARDS

Automobile Gasoline Model	Secondary Elasticity Estimates	
	Without CAFE Standards	With CAFE Standards
FEA-Faucett	0.15	0.11
Sweeney Auto	0.46	0.17
Wharton MOVE	0.21	0.19

^aCorporate average fuel efficiency

Additional fuel efficiency standards are expected.

Other efficiency standards are being or will be promulgated in the energy area. Building energy performance standards (BEPS) and appliance efficiency standards preempt the role of prices in motivating fuel efficiency increases. The standards produce a shift in the demand curve and make demand less price sensitive. Thus in the residential and commercial sectors, these standards can be expected to reduce demand elasticities while reducing consumption.

Characterizing Uncertainty

There is uncertainty associated with the elasticity estimates.

There is a range of uncertainty associated with any demand elasticity estimate; the actual elasticity could be greater than or less than any of the point estimates presented here. While there was general agreement that the range of uncertainty is not the same as the range of elasticity estimates, measures of the uncertainties implicit in the estimates were not explicitly calculated.

An exception was the Manne-Wilson analysis. With this specification, the dotted lines in Figure 9 represent 80 percent confidence bounds--based upon the recent data--around the mean long-run elasticity estimates for various assumed adjustment speeds. One

cannot, however, use the Manne-Wilson analysis to infer quantitative measures of uncertainty associated with other aggregate elasticity estimates.

Measures of uncertainty in elasticity were not calculated.

Several sources of uncertainty exist in each model--measurement error in historical data, parameter estimation uncertainty, specification errors in formulating the model, and errors in engineering judgments. However, limitations in the current state of the art either preclude calculation of explicit uncertainty measures or make calculation extremely costly. Furthermore, the objective measures of uncertainty which could be conceptually calculated can never be expected to capture the subjective uncertainties in the minds of many potential model users or modelers. For these reasons, the goal of developing a satisfactory measure of uncertainty has not been reached within this study. Lau proposes such a measure and describes an appropriate estimation methodology in Volume 2 Chapter 10.

RECOMMENDATIONS

Based upon its findings, the working group makes the following recommendations.

The EIA should develop standard definitions for energy demand data and elasticities.

The Energy Information Administration (EIA) should undertake the development of consistent accounting conventions and standardized data designed in close coordination with modelers. Reconciliation of disparate energy data sources among the various federal agencies should be a part of this activity. Model comparisons and interpretations are made difficult by the diversity of accounting conventions. Sectoral definitions vary among models. Historical data purportedly measuring the same concepts vary among federal agencies, e.g., gasoline data reported by the Federal Highway Administration and the EIA. The working group spent a great deal of time on standardizing the data without fully succeeding.

Modelers should publish more complete descriptions of their models.

Modelers should improve their practice in publishing assumptions, error statistics, robustness tests, validity tests, descriptive information, and historical data supporting their models. Agencies funding model development should insist on and support this

effort. Some such improvements in disclosure practices are costly to implement; this increased cost must be taken into account when planning a modeling project. Others, however, are less costly. For example, an econometrician estimating alternative specifications of one relationship should publish parameter estimates for all or a range of the specifications tried rather than simply the one or two "preferred" equations. While simple disclosure would not be very costly, it would greatly help users evaluate the robustness of crucial parameters. Similarly, publication of historical data supporting the model would allow other researchers to attempt duplication of the results, test alternative specifications not reported, and detect differences stemming from different sets of historical data used by different modelers.

Implicit aggregate elasticity estimates should become a standard part of model documentation.

Modelers should make aggregate elasticities a standard component of demand model documentation. The EIA should publish a set of definitions and computational procedures for calculating these elasticities. It is recommended that aggregate demand elasticities at three levels--primary, secondary, and, if possible, delivered--be disclosed, based upon model simulations. These elasticities should be reported for total demand and the various sectors modeled. Since aggregate elasticities depend upon the composition of price changes, tables of fuel-specific own and cross elasticities of demand should also be reported as standard components of model documentation. Since elasticities vary over time, these statistics should be reported for short, medium, and long time horizons.

Modelers should develop and utilize techniques for describing uncertainties in their models.

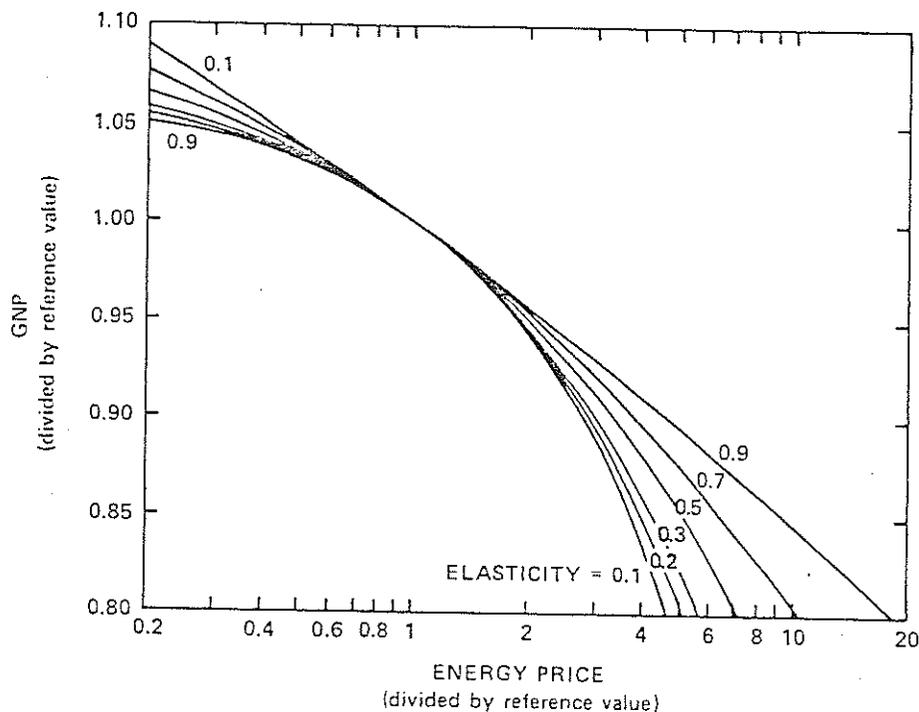
Recognizing the difficulty of adequately dealing with uncertainty in projections, the working group recommended that modelers develop and then consistently utilize techniques for describing the uncertainties in their models. This will require basic research to develop the methodology. Funding organizations and modelers, realizing that analysis of uncertainties is costly but important, should budget sufficient funds for this activity.

NOTES

1. EMF Report 1, Energy and the Economy, Volume 1, Energy Modeling Forum, Stanford University, Stanford, California, September 1977.
2. This differs from some definitions where own-price elasticities are negative, reflecting the inverse relationship between demand and price.
3. The decrease in consumers' surplus resulting from an energy tax is greater for larger elasticities. In the case of an increase in imported energy price, the additional wealth transfer to oil exporting nations is much smaller for a larger elasticity, offsetting the larger decrease in consumers' surplus.
4. Sweeney, James L., "Energy and Economic Growth: A Conceptual Framework," in Directions in Energy Policy: A Comprehensive Approach to Energy Resource Decision-Making, B. Kursunoglu and A. Perlmutter (eds.), pp. 115-140, Cambridge, Mass.: Ballinger Publishing Company, 1979.
5. The elasticity of substitution is defined as the rate of change of the ratio of energy inputs to other inputs, e.g., capital and labor, with respect to changes in the relative prices of those input factors. For value shares of energy in the economy less than 0.1, the two elasticities differ by less than 10 percent. The elasticity of substitution is the key parameter in a seminal model of energy-economy interactions. See Hogan, W. W., and A. S. Manne, "Energy-Economy Interactions: The Fable of the Elephant and the Rabbit?" Energy and the Economy, Volume 2, Appendix B, Energy Modeling Forum, Stanford University, Stanford, California, September 1977.
6. For this graph, it is assumed that the levels of capital and labor inputs to the economy and the state of technological progress in any year are independent of the price of energy. These assumptions focus on the aggregate economic costs of restricting energy use below the GNP maximizing level, not on the wealth redistributive aspect of changing energy prices. These results are based on a model, see note 4, that assumes the elasticity of energy demand is constant for a wide range of price changes, including prices far outside the historical experience. This is a convenient assumption but may be erroneous for large price changes like the 10- to 20-fold increases shown at the extremes of Figures 2 and 3. Similarly, this model assumes optimizing behavior on the part of energy consumers.

It is also assumed in Figure 3 that the decrease in secondary energy use is the result of an increase in the price of energy not related to an increase in its cost, such as an excise tax on secondary energy use. Conversely, if the price increase is the result of an increase in the cost of obtaining energy, such as an increase in the price of oil imports or in the cost of producing domestic supplies, Figure 10 is appropriate. In this latter case, for a given cutback and value for the aggregate elasticity, the GNP decrease is much greater than in the previous case; more of society's nonenergy inputs (capital and labor) must be directly utilized to produce/purchase the remaining energy supplies.

7. The averaging is based upon fixed quantity weights equal to their base case values. This is generally referred to as a Laspeyres price index.
8. In electricity generation, the heat value of fossil fuel inputs is roughly three times the heat value of the electricity produced.



Note: Energy use and price measured at secondary level

Figure 10 Relationship between Energy Price and GNP as a Function of Aggregate Elasticity for the Cost Increase Case

9. This example used energy input quantities and output prices. The price index, therefore, requires averaging output prices based upon output quantities--here all one. Alternatively, input prices can be used. In such case, the magnitude of the price change is reduced by a factor of three while its coefficient is increased by an identical factor. All resultant elasticities will be unchanged.
10. Diewert, W. E., "Application of Duality Theory," in M. E. Intrilligator, Frontiers of Mathematical Economics, Volume 3, 1978.
11. Hudson, E. A., and D. W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975-2000," Bell Journal of Economics, Volume 5, No. 2, Autumn 1974.
12. Lau, L. J., "A Note on Exact Index Numbers," Department of Economics, Stanford University, Stanford, California, March 1977.
13. Here GNP is defined as that portion of total output value of the rest of the economy not used to produce or purchase energy. Hence, GNP is the output available for final consumption and investment.
14. It is at this point that consumer choices are made and, with appropriate disaggregation, the products and choices of consumers are most nearly homogeneous.

15. These curves were generated under the assumption that markups between the secondary point and the retail point are additive. To the extent that some of the markups are multiplicative, the difference between secondary and delivered elasticities will be smaller than indicated in the graph. The curves were calibrated as follows:

$$\eta_R = \frac{\partial q}{\partial P} \cdot \frac{P_R}{q}$$

$$\eta_S = \frac{\partial q}{\partial P} \cdot \frac{P_S}{q} = \eta_R \frac{P_S}{P_R}$$

where η_R = retail elasticity
 η_S = secondary elasticity .

From Volume 2 Chapter 4, the 1972 price of secondary energy (P_S) was equal to \$1.43 per million Btu (1978 dollars). Taking retail as the aggregate price delivered to all consumers--from Hogan, Volume 2 Chapter 13--the 1972 price of retail energy ($P_R = P_S + 1.39$) was \$2.82 per million Btu (1978 dollars). Therefore,

$$\frac{\eta_S}{\eta_R} = \frac{P_S}{P_S + 1.39}$$

The 1980 secondary price of \$3.50 per million Btu (in 1978 dollars) was obtained by inserting industrial fuel prices for January 1980 from the May 1980 issue of the U.S. Department of Energy "Monthly Energy Review" into the industrial sector aggregation formula given in Hogan, Volume 2 Chapter 13.

16. This taxonomy of energy models was first suggested in "Energy System Modeling and Forecasting," by K. C. Hoffman and D. O. Wood in Annual Review of Energy, Volume 1, J. J. Hollander (ed.), Palo Alto, Calif.: Annual Reviews, Inc., 1976.
17. Results from a variant of the FOSSILL model, denoted the FOSSILL Conservation model, were also examined in the study. It employed disaggregated elasticities twice as large as in the baseline FOSSILL system.
18. The Griffin OECD and Pindyck models were estimated with OECD (Organization for Economic Cooperation and Development) cross-sectional data. However, only the U.S. portions of these models were utilized in the present study.
19. Modeling Resource Group of the Committee on Nuclear and Alternative Energy Systems, "Energy Modeling for an Uncertain Future," National Research Council, Washington, D.C., 1978.
20. The price of oil is measured at the refinery input, the price of gas at the city gate, and the price of coal delivered to electric utilities. The price of nuclear fuel is for enough fuel to provide 10^6 Btu (293 kWh) of electricity at the busbar times a nuclear fuel-to-electricity conversion efficiency of 0.36.

21. In reporting the results of the experiment, the modelers were asked to use the following primary and secondary points of measurement.

Primary Energy

- Oil and Gas: Includes shale oil and biomass. Quantity of oil measured at the refinery input; quantity of natural gas measured at the city gate. Composite price measured at the refinery input.
- Coal: Quantity of coal measured after cleaning; price measured delivered to electric utilities.
- Nuclear: Includes nuclear, solar, geothermal, and hydroelectric generation, as well as geothermal and solar heat. Primary energy equivalents (quantities) for nonfossil energy sources that are converted to electricity are computed as the amount of electric energy generated using the resource divided by the approximate thermal efficiency for electricity generation from fossil fuels equal to 0.36. Primary energy equivalents for non-fossil energy sources that are used directly as thermal energy are computed as the amount of fossil fuel energy replaced. This is assumed to be at the rate of $(1/0.36)(1.09) = 3.03$ input Btu/end-use Btu. This assumes 100 percent efficiency for replacement of delivered electricity, accounts for a 9 percent transmission loss, and converts to fossil input equivalent. In both cases, the price for the primary energy input is computed as the price of enough nuclear fuel to provide 10^6 Btu (293 kWh) of electricity at the busbar times a nuclear fuel-to-electricity conversion efficiency of 0.36.

Secondary Energy

- Oil and Gas: Quantity of oil measured at the refinery output; quantity of natural gas measured at the city gate; composite price measured at the refinery output.
- Coal: Net of coal used for electricity generation and synthetic fuels production; price measured delivered to industry.
- Electricity: Includes geothermal and solar heat. Quantity and price of electricity measured at the busbar. Primary energy equivalents for nonfossil energy sources that are used directly as thermal energy computed at 1.09 input Btu/end-use Btu. This assumes 100 percent efficiency for replacement of delivered electricity and accounts for a 9 percent transmission loss.

22. The following equation was estimated by least squares:

$$\ln \frac{E}{GNP} = C - \epsilon \ln P_E,$$

where E = aggregate energy demand,

GNP = gross national product,

C = constant,

ϵ = aggregate elasticity, and

P_E = aggregate energy price.

23. The ETA-MACRO model explicitly includes an aggregate elasticity parameter. That parameter is defined in terms of a Btu-weighted index with proportional price increases. Electricity price and demand are measured at the busbar, but the price and demand for oil and gas are measured at the refinery input. Thus, in the parlance of the current study its point of measurement is somewhere between the primary and secondary levels. The value for this parameter assumed in the present study is 0.25. The Paasche index aggregate secondary elasticity estimate as calculated here is 0.18 and the Btu-weighted estimate as calculated here is 0.35.

BIBLIOGRAPHY

- Anderson, C. J. Energy Policy Model: A Brief Overview. Livermore, Calif: Lawrence Livermore Laboratory, March 1979. UCRL-52672.
- Baughman, M. L., P. L. Joskow, and D. P. Kamat. Electric Power in the United States: Models and Policy Analysis. Cambridge Mass.: MIT Press, 1979.
- Carhart, S. C., S. S. Mulherkar, and U. Sanborn. The Brookhaven Buildings Energy Conservation Optimization Model. Upton, N.Y.: Brookhaven National Laboratory, January 1978. BNL 50828.
- Dartmouth System Dynamics Group. FOSSIL: Documentation, FOSSIL: Introduction to the Model, and FOSSIL: Technical Appendix. Hanover, N.H.: Thayer School of Engineering, Dartmouth College, July 1977.
- Difiglio, C., and D. Kulash. Marketing and Mobility: Report of the Panel of the Inter-Agency Task Force on Motor Vehicle Goals Beyond 1980. Washington, D.C.: Government Printing Office, March 1976. 1976-211-173/472.
- Energy and Environmental Analysis, Inc. Industrial Sector Technology Use Model (ISTUM): Industrial Energy Use in the United States, 1974-2000. Washington, D.C.: U.S. Department of Energy, October 1979. Contract #EX-76-C-01-2344, Volumes 1-4.
- Griffin, J. M. Energy Conservation in the OECD: 1980-2000. Cambridge, Mass.: Ballinger Press, 1979.
- Hirst, E., and J. Carney. "The ORNL Residential Energy Use Model." Land Economics, Volume 55, No. 3, August 1979. pp. 319-333.
- Jackson, J., S. Cohn, J. Cope, and W. F. Johnson. The Commercial Demand for Energy: A Disaggregated Approach. Oak Ridge, Tenn.: Oak Ridge National Laboratory, April 1978. ORNL/CON-15.
- Lukachinski, J., P. J. Groncki, R. G. Tessmer, R. J. Goettle, and E. A. Hudson. An Integrated Methodology for Assessing Energy-Economy Interactions. Upton, N.Y.: Brookhaven National Laboratory, October 1979. BNL-26452.
- Manne, A. "ETA-MACRO: A Model of Energy-Economy Interactions." In Modeling Energy-Economy Interactions, C. J. Hitch (ed.), pp. 1-45. Washington, D.C.: Resources for the Future, 1977. Also appears in Advances in the Economics of Energy and Resources, R. Pindyck (ed.), Chapter 9. Greenwich, Conn.: JAI Press, 1978.
- Parikh, S. C. A Welfare Equilibrium Model (WEM) of Energy Supply, Energy Demand, and Economic Growth. Stanford, Calif.: Systems Optimization Laboratory, Department of Operations Research, Stanford University, March 1979. SOL 79-3.
- Pindyck, R. The Structure of World Energy Demand. Cambridge, Mass.: MIT Press, 1979.
- Schink, G. R., and C. J. Loxley. An Analysis of the Automobile Market: Modeling the Long-Run Determinants of the Demand for Automobiles. Washington, D.C.: Department of Transportation, December 1979. DOT-TSC-NHTSA-79-49, Volumes 1-3.

Sweeney, J. L. "The Demand for Gasoline in the United States: A Vintage Capital Model." In Workshops on Energy Supply and Demand. Paris: Organization for Economic Cooperation and Development, 1978.

U.S. Department of Energy, Energy Information Administration. Project Independence Evaluation System: Documentation. Washington, D.C.: Department of Energy, September 1977. Volumes 1-7.

As shown in the Table of Contents, the several chapters, 2-13, are contained in Volume 2 of this report. A copy of Volumes 1 and 2 under one cover may be obtained from:

Energy Modeling Forum
Terman Engineering Center
Stanford University
Stanford, California 94305