TESTIMONY

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PP. 9.1

presented to

THE INVESTIGATIONS AND OVERSIGHT SUBCOMMITEE

of the

U.S. HOUSE OF REPRESENTATIVES

SCIENCE AND TECHNOLOGY COMMITEE

JUNE 2, 1981

In introduction to my remarks on energy demand modeling I would like to indicate my view of the role of formal economic modeling. Although my coments will be directed toward energy demand modeling, they could be applied to the modeling of any other aspect of our economy.

No models exist which allow us to develop precise dependable forecasts of energy demand. This limitation applies to use of both formal mathematical models and mental models. The reality is that we must make all of our planning and policy decisions while facing a high degree of uncertainty, an uncertainty which can be reduced but not eliminated by modeling activities.

Modeling activites <u>can</u> help us to recognize the real uncertainty that we face. Typically people tend to under-estimate the degree to which future events will diverge from their best projections. The cause-effect relationships are never understood precisely. In adddition, no model is complete; exogenous factors are typically taken as given. Yet these exogenous factors in many cases are the crucial elements driving the projections. As late as 1971, how many energy demand forecasts took into account the oil embargo, the Saudi decisions to limit oil production capacity, or the Iranian revolution? We cannot predict such surprizes. Yet systematic modeling can help us to sort out the implications of classes of surprizes and thus can help us to understand the extent of our uncertainty.

Policy and planning decisions can be aided by using models as "what-if? machines". We may have little confidence in our projections of oil demand in the year 2000 but may use models to help estimate _what_ will be the reduction in that demand _if_ we were to impose a 30% tax on the use of all oil. We can use models to evaluate _what_ may be the impact on world oil prices _if_ the OECD countries were aggressively to develop alternate energy sources or energy conservation technologies and programs. To do this successfully, we must have a firm understanding of the key cause-and-effect relationships governing the system.

Thus modeling is primarily for insights not primarily for precise projections.

These introductory remarks lead me to my comments on energy demand modeling. I would like to outline briefly the several most important factors in projections of future energy demand and proceed to discuss in greater detail one of these factors -- the response of demand to price.

Three sets of factors seem to be the most crucial determinants of demand growth:

- The rate of our economic growth and the patterns of that growth.

- Increases in energy prices and responses of energy users to those increases.

- o Policy induced energy conservation and its efficacy.

As the economy grows, so does the demand for all productive inputs, including energy. These demands tend to grow roughly proportionately to economic growth if all other factors (such as energy prices) were to remain constant. This point can be illustrated by Figure 1 which plots both energy demand changes and real (that is, inflation adjusted) GNP changes on a year-by-year basis. Clearly, fluctuations in the economy lead directly to fluctuations in energy demand. This phenomenon is evident in longer run trends as well, as illustrated by now familiar graphs which show the ratio of energy to GNP (the energy/GNP ratio) as drifting only slowly over time.

The GNP growth, of course, is not the only issue. Changing technology, environmental concerns, consumer preferences, energy prices, and public policies lead to shifts in the composition of economic activity and with these shifts, changes in the energy/GNP ratio. In most forecasting exercises changing technology, environmental concerns, and preferences are treated as exogenous factors _if_ they are treated at all, since even the _directions_ of such changes are extremely difficulty, at best, to predict.

With all factors held constant, energy demand grows roughly in

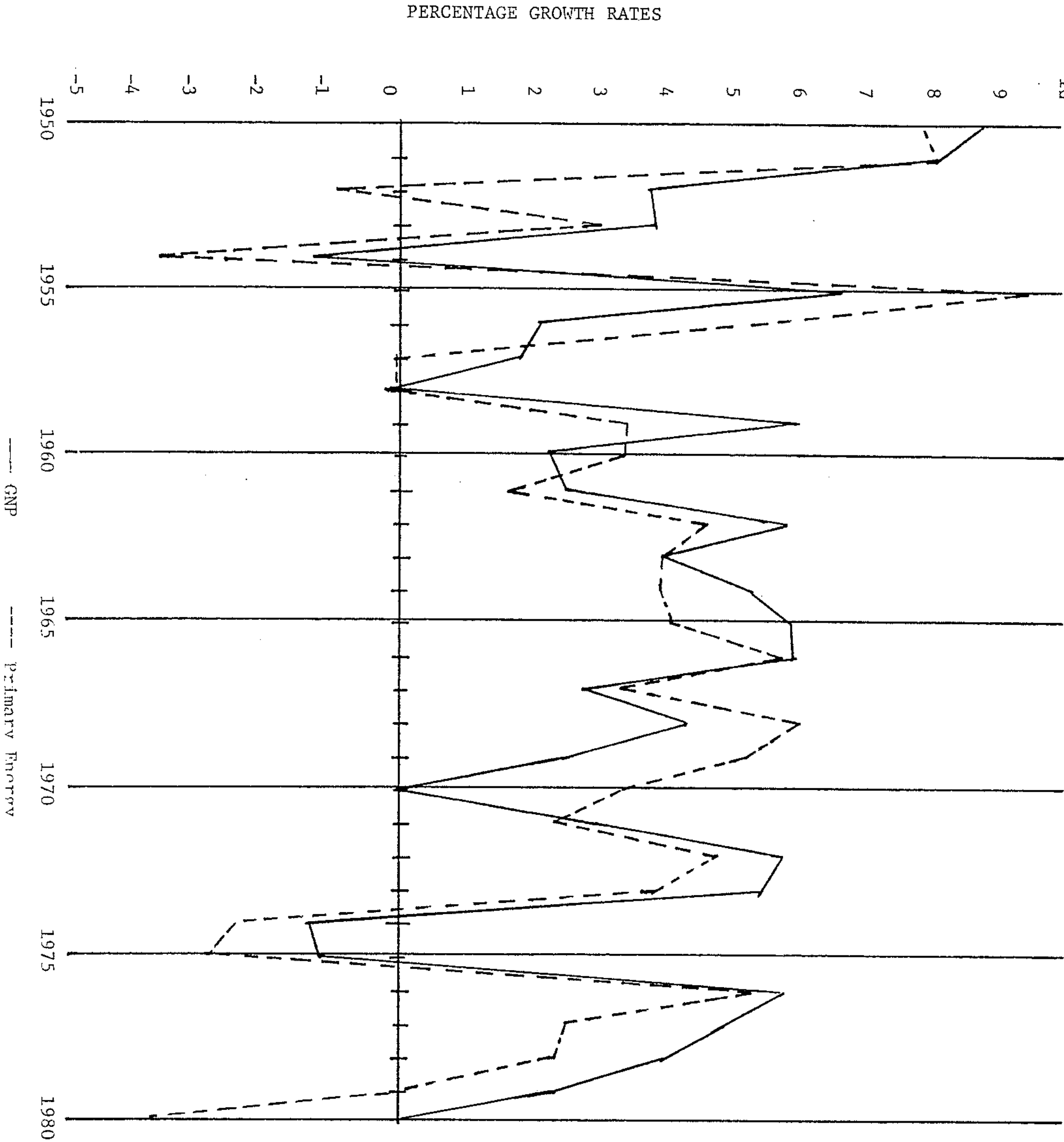


FIGURE 1

U.S. Energy Growth Rates vs Economic Growth Rates proportion to economic growth. This can be expressed in terms of the "elasticity" of energy demand with respect to GNP. This elasticity is defined as the percentage increase in energy demand stemming from a 1% increase in economic activity _with all other factors held constant_. Most studies have found the elasticity of energy demand with respect to economic activity to be roughly unity. Thus the energy/GNP ratio remains roughly constant over time if all other factors are unchanging.

This conventional elasticity definition should be differentiated from the unfortunate terminology which has crept into some energy policy discussions, particulary in the international energy policy community. One hears about nations adopting policies to keep their "income elasticities" of energy demand below some number, for example, 0.4. That "elasticity" is defined as the percentage rate of energy growth per unit of GNP growth, _allowing all other factors to vary_, in particular, allowing for the effects of higher energy prices and the impacts of policy induced energy conservation.

The difference between the 1.0 elasticity of demand with respect to GNP and an "income elasticity" goal of 0.4 reflects the projected or desired impacts of at least two additional factors, increased energy price and policy induced energy conservation.

For a given level of GNP, the quantity of energy demanded depends upon the mix of products produced, the inputs used in that production, the operating characteristics of these products, and the choices of consumption goods. Since these are for the most part matters of choice, each can be influenced by the energy prices and policy actions. Thus, for projecting energy demand it is crucial to project the prices of energy, the degree to which energy users respond to price changes, the energy conservation policies, and the efficacy of these policies in changing behavior.

Energy conservation policies can significantly influence energy demand, although their impacts are often quite difficult to quantify. For example, the corporate average fuel efficiency standard on new cars has pushed manufacturers toward downsizing automobiles far more quickly than would have occurred in their absence. Therefore the current stock of autos is more fuel efficient and U.S. drivers consume less fuel than would be the case if these standards were never legislated. Other policies such as weatherization, appliance labeling, or energy conservation tax credits may also influence energy demand. Thus the degree to which such policies are implemented and their efficacy once implemented must be factored into energy demand forecasts.

Although policy-induced energy conservation may significantly alter demand, the past and possible future energy price increases can be expected to lead to even greater reductions. The degree to which energy demand responds to prices can be quantified in terms of price elasticities. The price elasticity of energy demand is defined as the percentage reduction in energy demand produced by a 1% increase in energy price, with all else held constant. By this convention, price elasticities are typically positive numbers.

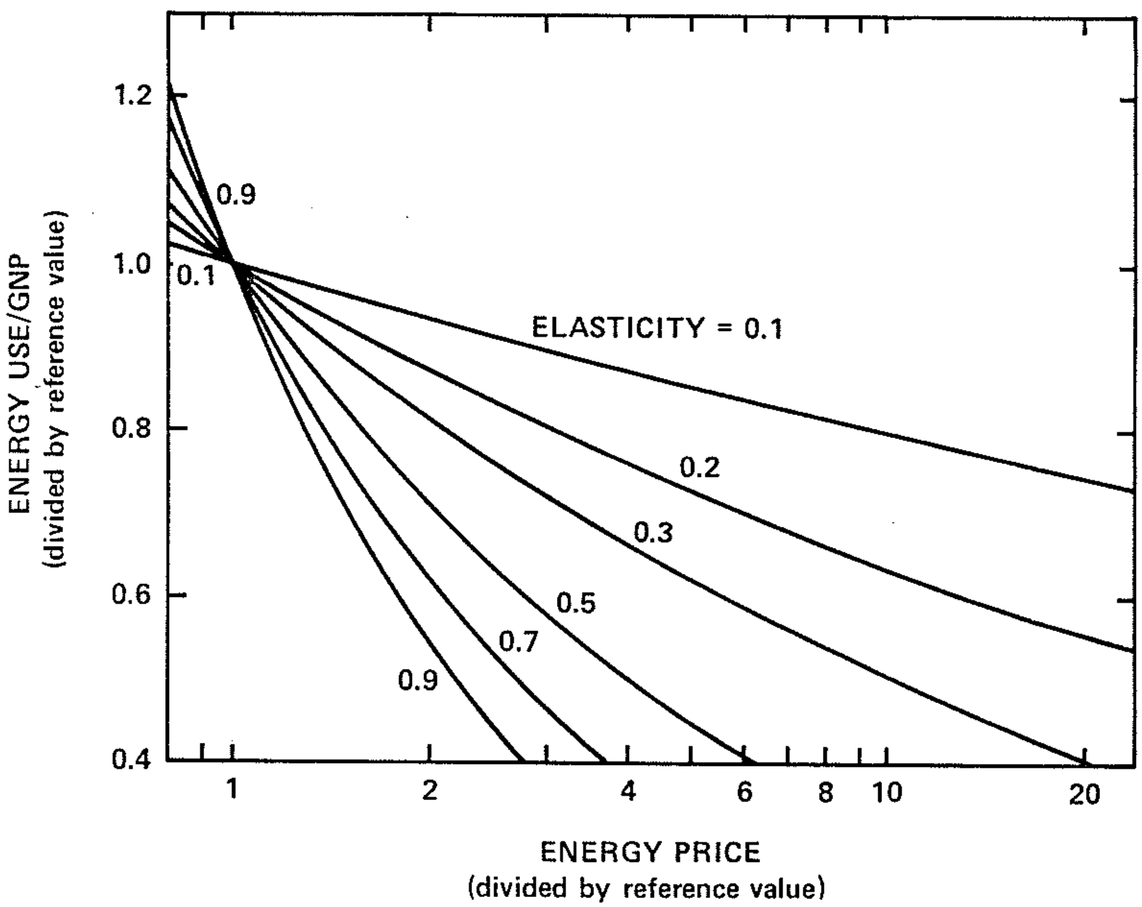
If energy prices increase, the energy/GNP ratio will decline over time. The magnitude of this decline depends crucially upon the price elasticity of demand for energy.

The significance of price changes and price elasticities is illustrated in Figure 2 which graphs the energy/GNP ratio as a function of energy price, for price elasticities ranging from 0.1 to 0.9. The coordinates are standardized at unity in order to facilitate examination of fractional changes in the energy/GNP ratio. If the price elasticity of demand is as low as 0.1, then a tripling of energy price will lead to a 10% reduction in the energy/GNP ratio. However, if the price elasticity is as high as 0.9, then the same increase in energy price will reduce the energy/GNP ratio by more than 60%.

Figure 2 can best be interpreted in terms of an aggregate price elasticity of energy demand: a measure of the degree to which some aggregate of all energy demand responds to some average price of all energy. This figure illustrates that forecasts of aggregate energy consumption depend crucially upon the implicit or explicit aggregate price elasticity.

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.

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

For this reason detailed elasticities by fuel are important for projecting demands for specific fuels such as oil, gas, or coal. Hence any full-scale analysis or forecast will depend upon the detailed set of fuel-specific elasticities. Unfortunately, there is less of a consensus about fuel-specific elasticities than about the aggregate price elasticity. Thus I will focus the remainder of today's comments on aggregate elasticities. These provide simple summary parameters, 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.

Even if we restrict attention to aggregate price elasticities, several issues must be resolved in order to communicate the likely magnitudes of these elasticities.

First is the issue of point of measurement. Since we could measure energy prices and quantities at many points in the energy system, inconsistencies in the point of measurement are pervasive in discussions of energy demand. One option is to measure aggregate energy demand or aggregate energy demand elasticities as close to the point of consumption as possible. However our aggregate statistics generally measure total energy at an earlier point in the supply chain. Two generic points within the energy system where total energy has been measured include: (1) before electric generation and other conversion losses, and (2) after these losses have been removed. The Bureau of Mines historically referred to energy measured at (1) as gross energy inputs and at (2) as net energy inputs. Here I refer to these quantities as primary and secondary energy, respectively.

The differences in elasticities due only to point of measurement can be illustrated for the simple case in which there are price markups and energy conversion losses from point to point in the energy production/consumption chain. This is illustrated in Figure 3 which shows that there is a great difference between elasticities measured at the two points but that this difference can be expected to decline as energy prices increase. The elasticities I will quote are all measured at the secondary level.

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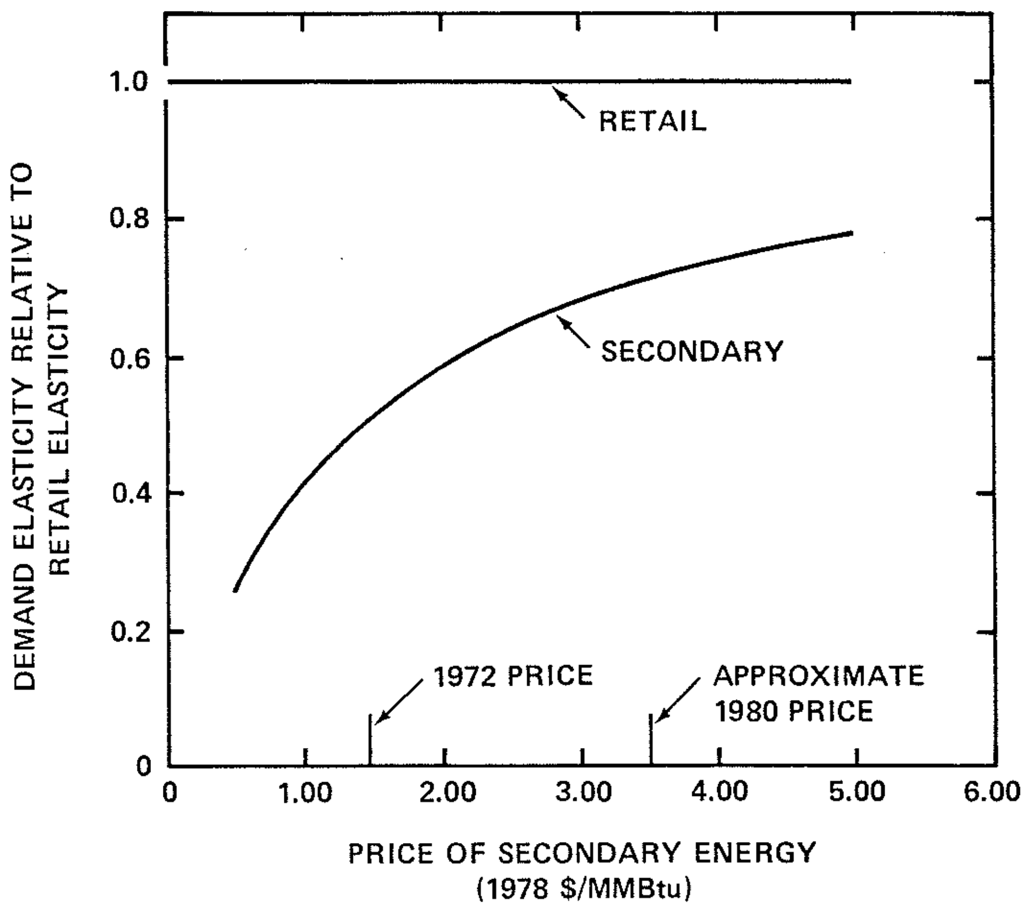
RATIO OF SECONDARY AND RETAIL ELASTICITIES AS A FUNCTION OF SECONDARY ENERGY PRICE



A second problem in interpreting price elasticities is that of adjustment dynamics. In general, since the capital stock of energy using equipment adjusts only slowly, short-run elasticities (1-5 years) may be expected to be considerably smaller than long-run price elasticities. The numerical estimates I will be presenting will be of long-run elasticities.

The Energy Modeling Forum (EMF) recently conducted a study which examined the aggregate price elasticity of 16 prominent energy demand models, those shown in Table 1. The models are described in detail in our report, "Aggregate Elasticity of Energy Demand", available through the EMF office, and reprinted in the current issue of The Energy Journal.

The models vary in scope, in methodology, in level of aggregation, representation of substitution possibilities, in treatment of energy supply and demand dynamics, and in the data and accounting systems used.

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 ISTUM

Table 1

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

model holds 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 or the Pindyck models implicitly allow all system adjustments to be captured in their parameter estimation.

Some models, such as the BECOM, the Hirst Residential, or the BESOM/Hudson-Jorgenson 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. Others, such the Baughman/Joskow, the Pindyck, or the Griffin models leave the substitution processes implicit.

The models also differ fundamentally in their approaches to parameter measurement. The model developers employed one or more of three basic approaches to parameter measurement: (1) statistical estimation of the aggregate fuel and/or sector price response, (2) detailed engineering specifications of alternative energy-using technologies, and (3) judgmental estimation of the aggregate fuel and/or sector price response. Table 2 indicates the primary methods used for parameter estimation.

Table 3 and Figure 4 present the mean long-run secondary aggregate price elasticity estimates from the participating models. The more comprehensive models, covering all energy using sectors, incorporating the full range of potential substitutions,

Table 2

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	

[a]Excludes the transportation sector and industrial feedstocks

[b]Only results from the automobile gasoline demand component were reported to the EMF.

[c]Combines both the statistical and engineering approach

Table 3

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				
Transportation[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
					ETA-MACRO	0.2
	BESOM/H-J	0.4			FOSSIL1	0.1
	Griffin OECD	0.5			FOSSIL1[d]	0.2
	MEFS	0.3			Parikh WEM	0.1
	Pindyck	0.7				

[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.

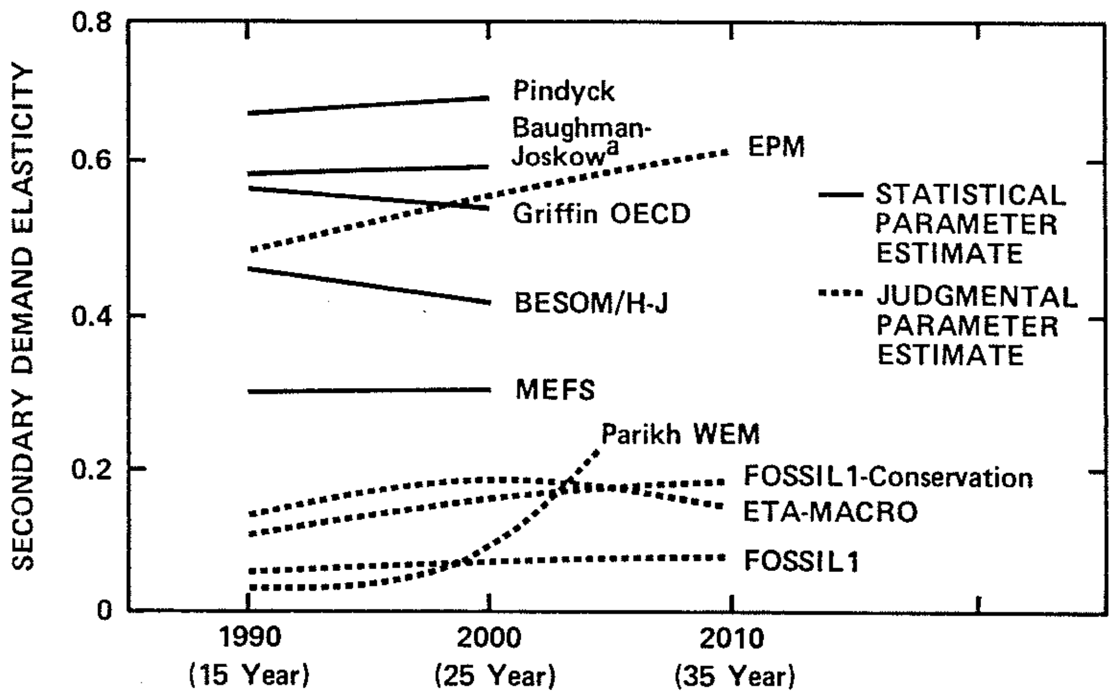
[c] Excludes the transportation sector

[d] FOSSIL1 Conservation

-Source: Energy Modeling Forum Study 4

FIGURE 4

AGGREGATE TOTAL DEMAND ELASTICITY ESTIMATES



Note: The Paasche index was used to calculate these estimates.
[a]Does not include transportation demands

and directly utilizing historical data to estimate the demand parameters were characterized by implicit long-run (year 2000) aggregate secondary price elasticities in the range of 0.3 to 0.7. These models are represented with solid lines in Figure 4.

The models that consider all consuming sectors, but employ judgmental parameter estimates, generally exhibit lower elasticity estimates. These models are represented with dashed lines in Figure 4. The sectoral models included in the study generally produced somewhat lower secondary elasticity estimates than the corresponding sectoral elasticities produced by the comprehensive models.

These numerical results demonstrate a surprising degree of consistency among the statistically estimated models. If these statistical models most correctly describe the future behavior of energy demand, then energy growth can be substantially decoupled from economic growth, energy conservation programs can effectively lower energy consumption, and energy supply development programs are less critical.

The judgmental models also show a surprising degree of consistency in their projected responses to higher energy prices, exhibiting low demand elasticities. If these models most correctly describe the energy system, then 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 critical.

The working group, after much debate, did not reach a consensus as to which class of models most accurately describes the world, although the vast majority believed that the higher estimates most correctly describe the world. My personal judgement is that the evidence strongly supports estimated long-run secondary price elasticities falling between 0.4 and 0.7.

We can expect an elasticity of demand with respect to GNP to roughly equal unity. Long-run aggregate secondary price elasticities of demand in the range of 0.4 to 0.7 seem most consistent with the existing evidence.

Yet we remain uncertain about future economic growth rates and even more uncertain about future energy prices. Imperfect knowledge about these factors implies a continued uncertainty about future energy demands. The quantities involved can be illustrated Table 4 which explores demand projections which are consistent with different sets of asssumptions. The first set of four demand estimates is based upon an assumption that the U.S. economy grows by 2.5% per year average between 1972 and 2000, while the second set assumes a 3.5% average. Two different price elasticities are given: 0.4 and 0.7. Finally, two different energy price increases (from 1972 to 2000) are assumed.

The demands for energy in the future will depend radically upon the level of economic activity, the energy price increases, and the price elasticity of demand for energy, as well as upon conservation policy. Thus, under the current state of knowledge we cannot forecast energy demand with any degree of precision either using formal models or by exercising our mental models.

In summary, three factors seem to be most critical for projecting energy demands: the rate of our economic growth and the patterns of that growth, increases in energy prices and responses of energy users to those increases, and the nature and efficiacy of policy- induced energy conservation.

TABLE 4

ILLUSTRATIVE ENERGY DEMAND PROJECTIONS AS ASSUMPTIONS VARY

Price Elasticity:	Price Increase 400%	Price Increase 200%	
Ø.4	8Ø Quad	1Ø6 Quad	Energy Demand with 2.5% annual GNP growth
Ø.7	53 Quad	86 Quad	

Price Elasticity:	Price Increase 400%	Price Increase 200%	
Ø.4	1Ø4 Quad	138 Quad	Energy Demand with 3.5% annual GNP growth
Ø.7	69 Quad	112 Quad	