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Survey of the Research into Energy-Economy Interactions

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PREFACE

Our "Survey of the Research into Energy-Economy Interactions" consists of two volumes. Volume I is divided into two parts: a survey of the literature on energy-economy interactions and a survey of energy-economy models. Volume II is an annotated bibliography containing abstracts of the nearly 400 articles, books and reports cited in Volume I.

Part I of this volume (Volume I) consists of a detailed and comprehensive review of recent (1960 to present) and on-going research into energy-economy interactions. The review focuses on the results from theoretical and empirical analyses of energy-macroeconomic interactions, the different methodologies used, and the conceptual problems in this research. The review is organized around a number of key energy variables impacting the economy. These variables include the supply of energy, the price of energy, the world price of oil, energy capital requirements, energy R&D, conservation regulations, and stockpiling.

Part II begins with a chapter summarizing energy-economy modeling. This chapter provides a conceptual framework for analyzing energy-economy models, discusses the general features and methodologies of a large number of models, and summarizes the state of the art in modeling energy-economy interactions. This survey chapter is followed by detailed reviews of six different energy-economy models: Manne's ETA-MACRO and ETA, Hudson-Jorgenson's LITM, PILOT, Wharton Annual Energy, Reister-Edmonds, and Berkeley (Glassey-Benenson). Each review describes the methodology and general features embodied in the model, summarizes the types of energy-economy interactions addressed, and assesses the capa-

bilities of the model.

This volume is the first in a two-volume report to the Macroeconomic Analysis Division of the Energy Information Administration. We thank the many authors who provided us with copies of their work and/or directed us to other research. We are indebted to our program manager, Dr. David E. Serot, for his guidance and encouragement. Our typist, Mrs. Dorothy McIlroy, eased our burden considerably by displaying both perseverance and perfection. Finally, we would like to express our appreciation to the Department of Energy for giving us the opportunity to create a single reference source for the burgeoning research into energy-economy interactions.

CHAPTER I

INTRODUCTION

Despite the now widespread recognition of the importance of energy-economy interactions, no framework yet exists for categorizing and analyzing these interactions. For the sake of definition and cohesiveness, we have developed two alternative means of viewing energy-economy interactions. The first focuses on the actual impacts of energy on the economy. Our list of the economy-wide aggregates influenced by energy is presented in Table 1-1. It includes aggregate economic output, the price level, labor, international trade and finance, capital markets, consumption-savings, and capital.

This categorization of energy-economy interactions offers several advantages. It easily encompasses all of the research even remotely related to energy and the economy, and it also provides for a quick and readily understandable summarization. However, to some extent it puts the proverbial cart before the horse, since it deals only with effects rather than with causes.

For that reason, our second approach to synthesizing the literature on energy-economy interactions begins with a breakdown of the key energy variables (parameters) causing changes in the economy. The following seven broad energy variables can potentially alter the course of the economy:

- Growth rate of energy supply
- Cost of domestic energy production and associated capital requirements

TABLE 1-1

ENERGY-ECONOMY INTERACTIONS

I. Aggregate Economic Output

- A. GNP
- B. RANNP (Resource adjusted net national product)

II. Price Level

III. Labor

- A. Unemployment rate
- B. Labor force participation
- C. Total labor force
- D. Productivity
- E. Wages

IV. International

- A. Exchange rates
- B. Balance of payments
- C. Balance of trade
  - 1. Imports
  - 2. Exports
- D. Protectionism
  - 1. Tariffs
  - 2. Quotas
- E. Supply and demand for reserves

V. Capital Markets

- A. Term structure of interest rates
  - 1. Real
  - 2. Nominal
- B. Cost of capital
- C. Capital rationing
- D. Demand and supply of money

VI. Consumption-Savings

- A. Consumption/savings behavior
- B. Time preference and the consumption discount rate
- C. Savings-income ratios

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VII. Capital

A. Total investment
B. Types of investment
C. Profits
D. Price of capital
E. Capacity utilization

- Investment in energy R&D
- Price of energy products, including price controls and BTU taxes
- World price of oil
- Stockpiling to prevent short-run energy shortages
- Direct regulation for conservation

Clearly not all of these energy variables are independent of each other. For example, the growth rate in the energy supply depends upon government expenditures on R&D and the price of energy products. However, each of these seven energy variables impinges on the economy in some unique ways which will be discussed in the remaining sections of this survey.

CHAPTER II

SUPPLY OF ENERGY

The same facts often generate widely different theories. Take the nearly parallel growth in energy and the economy, for example. Hogan (1978a, 1978b) notes that between 1950 and 1973 (the year of the Arab oil embargo), GNP grew at 3.6% a year and energy consumption by 3.4%. This almost one-to-one correspondence between energy and the economy strongly implies some sort of causality.

Prior to the embargo, few people doubted the direction or degree of that causality -- energy closely tracked the expanding economy. However, the embargo raised serious questions about the availability of energy. Not coincidentally, it also thrust energy into the dominant role, with growth in the economy apparently constrained by the availability of energy. This chapter examines these ties between the energy supply (availability) and the economy.

AVAILABILITY OF ENERGY

Nordhaus (1973, p. 529) points out that concern over the adequacy of energy is actually only part of the "more general pessimism about the viability of economic growth on a finite world. This new and pessimistic view about economic growth holds that growth is limited by a finite amount of essential, depletable natural resources. In the process of consuming finite resources, the world standard of living descends inexorably toward that of Neanderthal man." The most noted proponents of this new view of growth include Forrester (1971), Mesarovic and Pestel (1974), Meadows,

et al. (1972), and Paul and Anne Ehrlich (1970).

Just how important are these resource constraints on growth? Nordhaus (1974b) attempts to answer this question by directly measuring the availability of resources. In calculating resource endowments, he notes that it is important to distinguish between three different measures of availability: (1) proved reserves, (2) ultimate recoverable resources, and (3) total crustal abundance. According to Nordhaus, much of the recent anxiety about our resources has been kindled by numerous studies showing very low proved reserves to current consumption. He feels these figures are unduly pessimistic since proved reserves are equivalent to the working capital or inventory of known resources.

On the other hand, the total crustal abundance measure inspires too much confidence because it is based upon the assumption of total recovery of all resources. Nordhaus recommends an in-between measure--ultimate recoverable resources. This economically relevant measure depends upon both technology and price. Using this measure, he concludes that the future will not be limited by the sheer availability of important materials. Addressing the narrower question of energy resources, he says (pp. 24-25) that "Even with only the current technology [fossil fuels and current nuclear and breeder technology] there are resources for more than 8,000 years at the current [1970] rate of consumption." The fossil fuels alone should last for 520 years.

Apparently in recognition of the uncertainty about long-run resource availability, the American Economic Association recently reprinted an article by Goeller and Weinberg (1978). In a preface to this article, Koopmans summarizes (p. 1) the approach taken by Goeller and Weinberg as follows:

> The authors have gone through the entire periodic system examining all the elements plus some important compounds, to determine the flow of their extraction in 1968, and estimate for each the total resources potentially available according to a rather generous definition of potential sources--the atmosphere, the ocean and a mile-thick crust of the earth. The ratio of total resources to demand in that year is expressed for each element in years to go until exhaustion at the constant 1968 rate of extraction--a simple signal of relative abundance or scarcity.
>
> On the basis of their scrutiny of these geological and technological data, Goeller and Weinberg pronounce the principle of infinite substitutability: With the exception of phosphorus and some trace elements for agriculture, mainly cobalt, copper and zinc, and finally the CH_x (coal, oil and gas), society can exist on near-inexhaustible resources for an indefinite period.

Goeller and Weinberg classify the depletion of resources into three stages. Stage 1 consists of present usage patterns and should persist for the next 30 to 50 years. In stage 2, lasting several hundred years, society depends upon coal since almost all oil and gas have been exhausted. Stage 3 ushers in the Age of Substitutability. All fossil fuel has been exhausted and society relies almost exclusively on materials that are virtually unlimited.

According to Goeller and Weinberg, of the thirteen most widely used elements, only extractable CH_x (coal, oil and gas) and phosphorus are not essentially inexhaustible. They say (p. 3) that "Shortages of almost all other minerals are of second order importance compared to shortages of CH_x." They conclude by stating (p. 9) that "depletion of mineral resources per se need not create catastrophe, provided man finds an inexhaustible, non-polluting source of energy. The main problem is how to go from our present stage, stage 1,...to stage 3...without incurring drastic social instabilities."

Judging from Goeller and Weinberg's comments, mankind has several hundred years to solve its problem of limited fossil fuels. Lest all

this sound too optimistic, the usual caveats need to be raised. As Long and Schipper (see U.S. Congress (1976)) note, Vogley's (see U.S. Congress (1976)) estimates of recoverable resources are 10 to 10,000 times smaller than those of Goeller and Weinberg. And Skinner's (1976) are 10 to 30 times smaller than those of Vogley. There is no direct way of determining how the assumptions underlying these sets of estimates differ. Moreover, all of these studies ignore a crucial issue -- the geographic distribution of resources. Brooks (1976) believes that the inability of the world's political systems to allocate resources across national (or even state) boundaries is far more important than the possibility of a physical shortage.

All of these studies address the broad issue of fossil fuel. However, in our present economy, energy is almost synonymous with oil. As a result, much of the debate about U.S. energy policy centers around the availability of petroleum. This debate has spawned several studies of future world oil supply and demand. Adelman and Jacoby (1978, p. 1), with tongue in cheek, summarize these studies as nearly all painting the following picture:

> Some day, like Old Mother Hubbard we will go to the cupboard and find it bare. The result will be a sharp, perhaps devastating, international crisis. There will be a wide gap between world needs and oil production, and consumers will be drawn into a "physical scramble" for "inadequate" supplies.

According to Adelman and Jacoby, the CIA (1977) study produces the most pessimistic projection, with a "gap" between supply and demand of 11 MBD by 1985. The WAES projections (see Basile and Sternlight (1977), Martin (1977), and Wilson (1977)) include several scenarios with a "gap" appearing as early as 1980 or as late as the late 1990s. Adelman and

Jacoby argue (p. 5) that in reality the very idea of a long-term "gap" is ludicrous. Such a gap can only exist if sellers deliberately hold "the price to much less than the traffic will bear. One searches in vain for an explanation of why or how, in any competitive monopolized market, sellers should insist on giving away a large fraction of the revenues available to them."

ECONOMIC OUTPUT

According to Solow (1974), the seriousness of the resource exhaustion problem depends upon two aspects of technology. The first is technological progress, especially natural resources-saving progress. The second is the ease with which other factors of production such as labor and capital can be substituted for energy in the production process.

If other factors can be easily substituted for natural resources, no problems arise even in the event of complete resource exhaustion. On the other hand, if little or no substitution is possible, resource exhaustion leads to catastrophes. Solow demonstrates the connection between substitutability and Doomsday. Using a simple aggregative model, he shows that:

- If the elasticity of substitution between exhaustible resources and other inputs is unity or bigger, and
- If the elasticity of output with respect to reproducible capital exceeds the elasticity of output with respect to natural resources, then,
- A constant population can maintain a positive constant level of consumption per head <u>forever</u>.

However, if the elasticity of substitution is less than one, then sustainable long-run consumption falls to zero. (This also occurs when the

elasticity of output with respect to capital is less than that for resources.)

Recognizing the importance of the elasticity of substitution to energy-economy interactions, Hogan (1978a, 1978b), Hogan and Manne (1977), and Manne (1978) devote considerable effort to documenting the impact of different elasticities on GNP. Figure 2-1 comes from Hogan and Manne (1977) and illustrates different elasticities of substitution. A zero elasticity corresponds to fixed proportions, i.e., a constant proportion of energy (in physical terms not dollars) to GNP. Total output can only be increased with proportional increases in both energy and nonenergy inputs. Therefore, energy availability constrains output. In other words,

GNP = Constant X Energy

In this extreme case, the energy elasticity of output equals one so that a 10% reduction in the supply of energy reduces output by 10%, a 20% reduction brings output down by 20%, etc.

The assumption of fixed proportions underlies much of the discussion of the energy crisis. The reasons for its widespread acceptance (if only subconscious) are fourfold. First, it appears at first glance to be supported by the actual record of the U.S. economy. Second, it possesses an intuitive appeal since it coincides with the well-known "fact" that energy is indispensable to every production process. Third, it matched the mood of much of the nation after the embargo. Fourth, it is easy to understand and to explain.

Lave (1978) notes that this belief in fixed proportions constitutes the first stage of conclusions regarding the effect of energy on GNP. Lave goes on to say (p. 129) that, "Fortunately, the elasticity of substi-

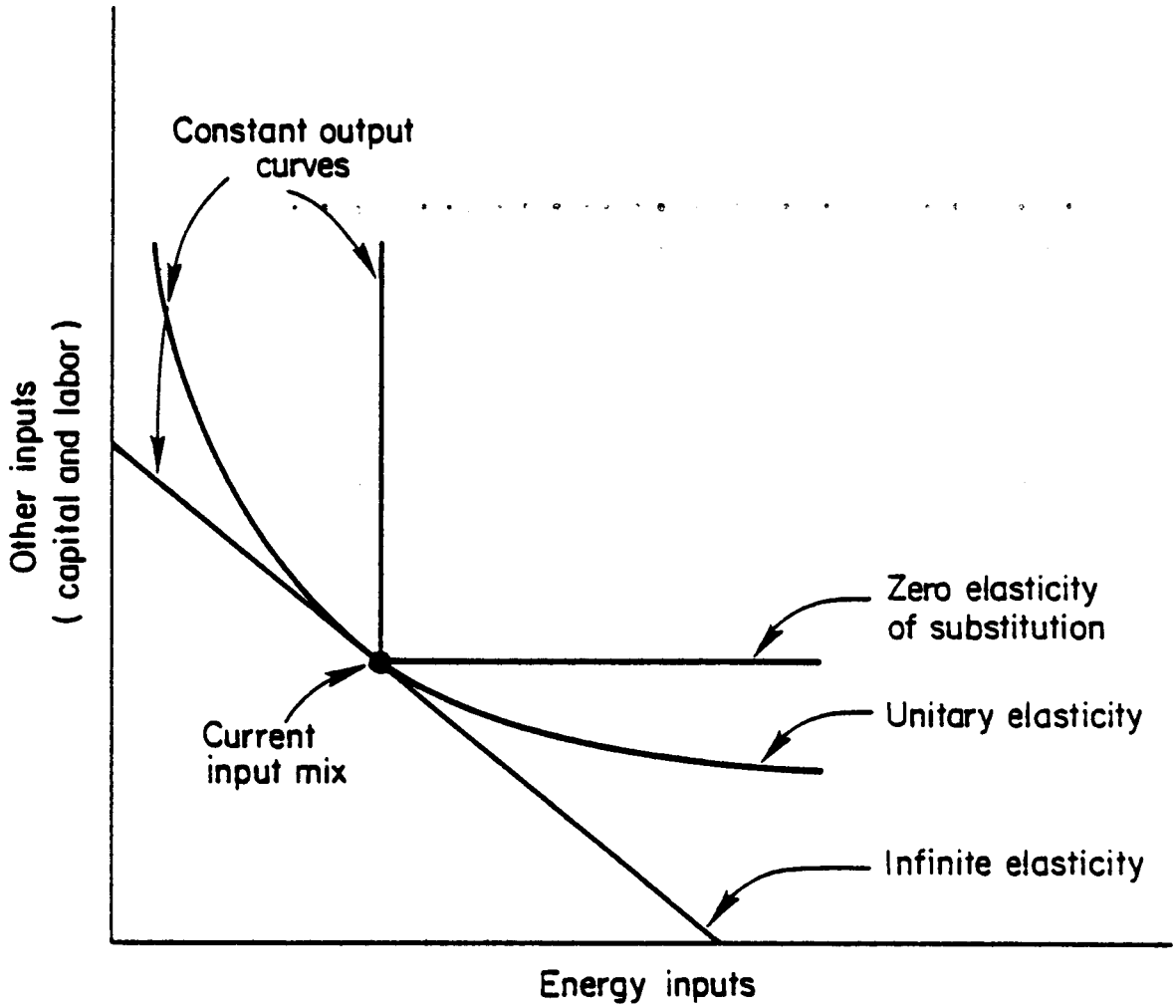


Figure 2-1. Different Elasticities of Substitution

Source: Hitch (1977, p. 251).

tution of energy for other inputs is not zero. Empirical work suggested elasticities of substitution as close to unity as to zero." Therefore, the second stage of energy modeling incorporates a non-zero elasticity of substitution.

A Simple Two-Sector Model

The literature on the theory of economic growth seems a logical place to look for models of energy and economic growth. Hahn and Matthews (1964) and then Britto (1973) have surveyed the enormous literature on economic growth theory. Somewhat surprisingly, not one of the 385 articles and books cited in these surveys explicitly examines the impact of energy on economic growth! In the short time since Britto's survey, a number of papers have appeared on the economics of natural resources (see especially the Summer 1974 issue of the Review of Economic Studies and papers by Bradley (1973), Lewis (1979), and Deshmukh and Pliska (1980)). But even this research ignores resource-economy interactions (except for Niehans (1975)).

Hogan (1978a, 1978b), Hogan and Manne (1977), and Manne (1978) seek to remedy this oversight in a series of closely overlapping papers. They develop a simple conceptual model of energy and economy. The essential ingredients of the model are an identity equating the value of inputs to those of outputs and a CES production function with two inputs -- energy and all other inputs. By assuming a constant energy cost and no change in other inputs, Hogan and Manne determine the impact of energy reductions on GNP in the year 2010.

Figure 2-2 shows the magnitude of these impacts. Assuming a growth rate of 3% a year between 1970 and 2010, GNP will be about $4,400 billion (in 1975 dollars) in 2010 and total primary energy input will amount to

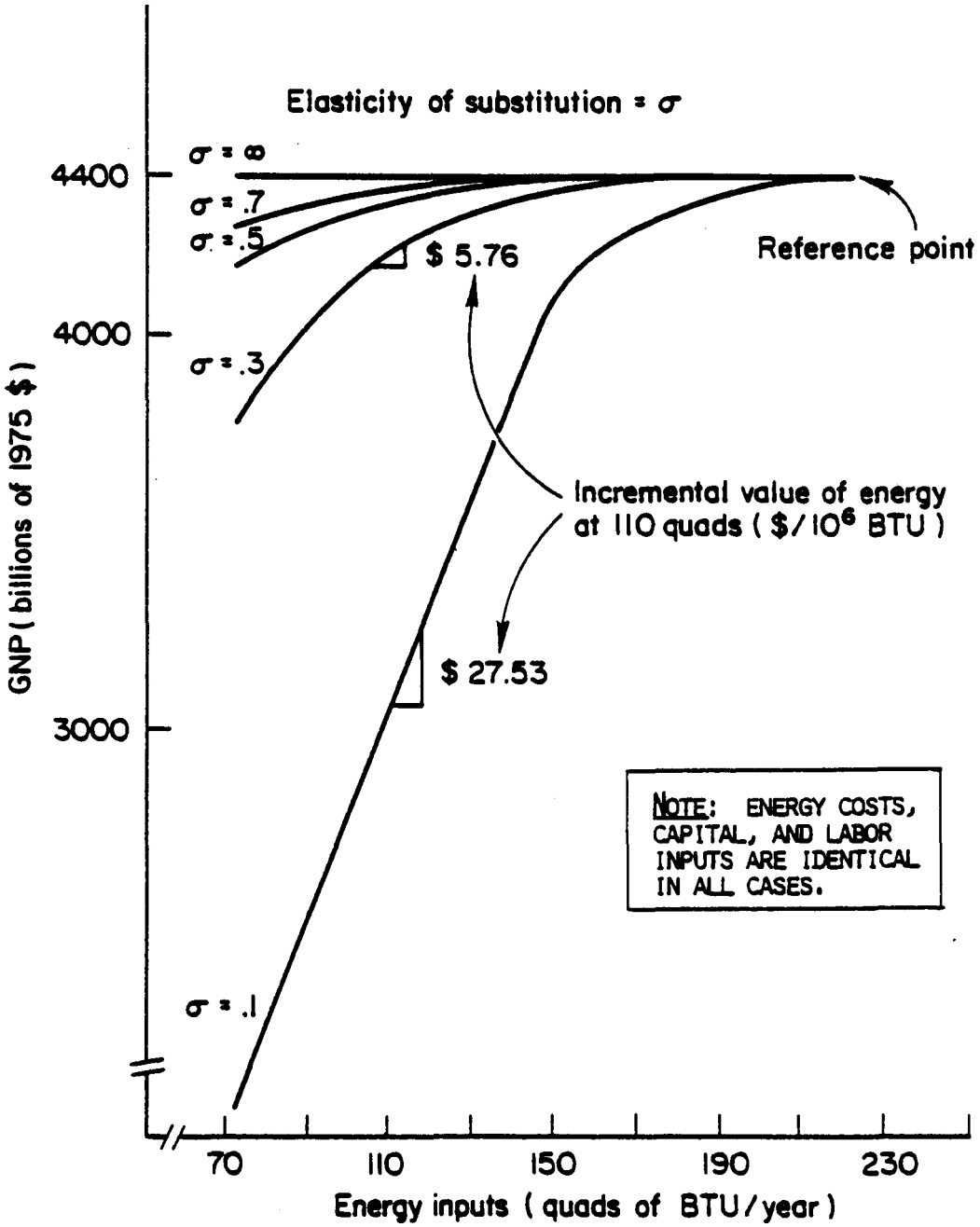


Figure 2-2. Economic Impacts of Energy Reductions in the Year 2010

Source: Hitch (1977, p. 254).

220 quads. Reductions in energy inputs produce widely different effects on GNP depending upon the long-run elasticity of substitution. A 50% cutback in energy causes a 28% reduction in GNP if the elasticity is only .1. If the elasticity equals .7, a 50% reduction in energy only trims GNP by 1%. (Time has a way of magnifying even these small losses in GNP. If the economy grows at 3% in real terms and future consumption is discounted at 6%, a 1% reduction in annual GNP corresponds to a loss of nearly half a trillion dollars in terms of present value.)

Judging from these widely disparate results, the elasticity of substitution provides a very important measure of the linkage between energy and the economy. The lower the elasticity, the more significant is the feedback between energy and the economy. Even small changes in this elasticity imply very large changes in the impact of energy on the economy (and vice versa).

Some Empirical Results from Energy-Economy Models

With the elasticity of substitution established as a key parameter in the energy-economy debate, Hogan and other participants in the Energy Modeling Forum next attempt to estimate this elasticity (Energy Modeling Forum (1977)). They base their estimates on the following energy models: PILOT, Kennedy-Niemeyer, Wharton, Hudson-Jorgenson, Hnyilicza, DRI-Brookhaven.

The EMF group agreed upon a standard set of assumptions for use in the analysis. These "driving variables" include population, labor force, labor productivity, capital costs, discount rates, technologies, etc. Then the EMF group defined a set of six different scenarios corresponding to different assumptions. The six scenarios are base case, declining oil

import price, high growth case, high growth with energy constraints, base case with energy constraints, and base case with BTU tax.

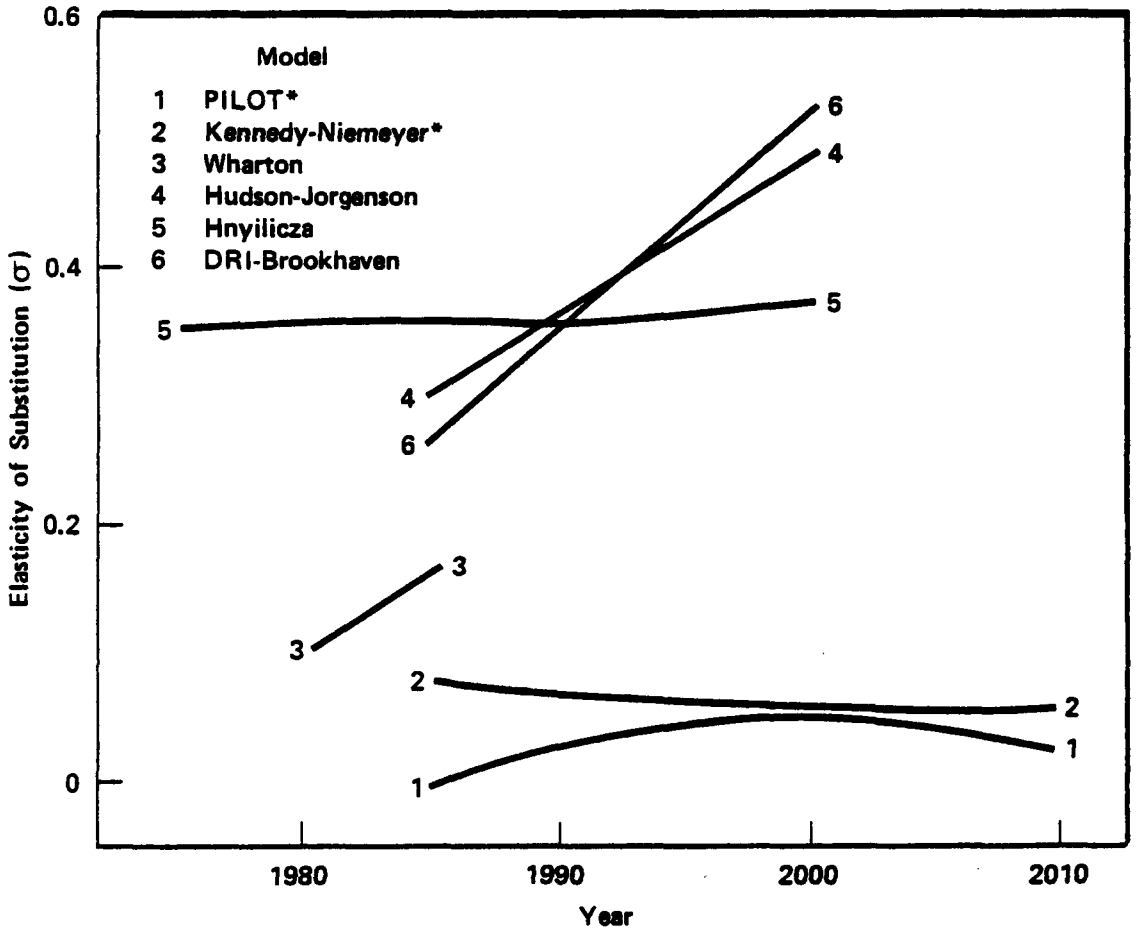
Results from simulations of the base and high growth cases provide the necessary input for calculating the elasticity of substitution inherent in each model. These elasticities are presented in Figure 2-3. Because of substantial differences in model structure and their varying stages of development, these estimates should be used with care.

Other Estimates of the Aggregate Elasticity of Substitution

Hogan and Weyant (1978), Hogan and Fromholzer (1977), and Weyant (1978) attempt to narrow the range of elasticities of substitution derived from the energy-economy models. The research by Hogan and Fromholzer closely resembles the work by Nordhaus and Tobin (1973) on the elasticity of substitution of natural resources. Nordhaus and Tobin test the ability of different production functions to replicate the behavior of the U.S. economy. The following functional form performs the best in these simulations:

$$Y = [a\{(A_K K)^{\varepsilon}(A_L L)^{1-\varepsilon}\}^{-\rho} + b\,(A_R R)^{-\rho}]^{-1/\rho}$$

Nordhaus and Tobin then estimate the magnitude of the parameters ρ and λ. Their regression results imply an elasticity of substitution between neoclassical factors and natural resources of about two -- a very high elasticity. Hogan and Fromholzer apply the Nordhaus and Tobin model to energy and obtain disturbing results. All of their estimates of ρ are less than -1, implying a negative elasticity of substitution. These unsatisfactory results lead them to question the model, the data, and/or the estimation procedures.



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

Figure 2-3. Aggregate Elasticities of Substitution of Different Energy-Economy Models

Source: Hogan (1978b, p. 22).

Hogan and Weyant (1978) turn next to energy sector models for estimates of the elasticity of substitution. They begin by making the important point that "The interpretation of the elasticity of substitution is aided by recognition of its virtual equivalence with the more familiar price elasticity of energy demand." Schurr (1978a) also notes that the "demand elasticity subsumes the elasticity of substitution...throughout the entire range of productive processes...."

Hogan and Weyant discuss two approaches to measuring the price elasticity in energy sector models. The first analytical approach calls for deriving the aggregate price elasticity from direct analytical transformations and aggregations of the disaggregated elasticities built into the detailed models. The second approach involves simulation of the models and use of the simulation results to compute the elasticity of substitution.

According to Hogan and Weyant, the analytical approach imposes extremely burdensome data and computational requirements on prospective users. In particular, complex aggregation rules must be derived relating the aggregate elasticity to individual product elasticities. These aggregation rules must somehow reflect differences among energy models, especially in regard to the definition of energy commodities, the point of measurement, the aggregation of demands, and even the specification of elasticity (in terms of average or marginal prices, long or short run, dynamic or static).

These problems with the analytical approach drive Hogan and Weyant to the simulation approach. They use eighteen different energy sector models to generate data for estimating the elasticity of substitution. However, even the simulation approach requires the use of aggregation rules for transforming the different prices and quantities for energy inputs

into a single price and quantity. Hogan and Weyant focus on three energy fuels -- coal, oil and natural gas, and nuclear fuel. The raw data from the simulations are derived by varying the primary energy input prices up and down by 25% (a total of nine different energy price cases). Hogan and Weyant then generate Tornquist indexes for aggregate energy prices and quantities from the simulated model results. They use these indexes to estimate the price elasticity, both for primary and secondary energy.

Weyant (1978) reports the results of this experiment. The estimates of the primary energy elasticity of substitution range from .25 to .61. Judging from all of the evidence presented so far, both from the energy-economy models and the energy sector models, the aggregate elasticity of substitution falls within a range of .2 to .6.

Some Complications

The results described so far depend upon a crucial assumption -- no change in nonenergy inputs. Given the long-term nature of the analysis, this assumption seems questionable. Recognizing this, Hogan (1978b) and Hogan and Manne (1977) also attempt to explicitly incorporate changes in capital. They do so by postulating a slightly more complicated aggregate production function with inputs of capital, labor, and energy. Here is Hogan's (1978b, pp. 13-15) rationale for this change:

> Reductions in energy input lead to changes in the rate of return on capital as well as reductions in the level of total output. Investment, savings, and capital use are altered as a consequence. Over time, these effects may cumulate into significant changes in the capital stock and, therefore, in the productive capacity of the economy.

Hogan attempts to incorporate these changes into his analysis by assuming that capital adjusts to maintain a constant rate of return rather

than remaining fixed in quantity. This adjustment in the capital stock magnifies the impact of energy reductions on economic output. Indeed, in this case, the indirect effect of the energy reduction via the change in capital exceeds the direct effect.

Obviously the energy-economy connection is more complicated than it first appeared. Energy affects GNP, the rate of return on capital, investment, savings, capital input, the capital stock, and the productive capacity of the economy. Changes in these variables in turn reverberate throughout the economy. Moreover, Lave (1978) argues that productivity growth probably differs across sectors, with manufacturing the fastest growing and services the slowest. Energy shortages lead to shifts in both production and consumption patterns with those shifts favoring services (low productivity and low energy use) over manufacturing (high productivity but high energy use). As a result, reductions in energy slow growth still further.

What began as a simple relationship between energy and the GNP has now become a complex set of interactions. As Lave (1978) and Schurr (1978a) point out, answers to questions about all of these energy-economy interactions must probably come from estimates of disaggregated elasticities of substitution. Some of these estimates are provided in the next chapter.

Energy Availability and Economic Output

Several models of energy-economy interactions have been used to study the impact of energy availability on U.S. GNP. Perhaps the best publicized results come from Manne's ETA-MACRO model.

Manne (1977) studies the macroeconomic effects of a "no-nuclear" policy. The model simulations are guided by the MRG assumptions about technologies and cost. Under these assumptions, nuclear energy in coal fired plants are both cost-effective for base-load electricity generation. As a result, a "no-nuclear" policy imposes no economic losses until coal supplies become a binding constraint in the year 2000.

After the year 2000, the MRG ground rules allow for the introduction of solar energy as a backstop technology. But the levelized cost of this backstop are 20 mills higher than coal or nuclear energy. Given these assumptions and an assumed elasticity of substitution of .25 between primary energy and other inputs, Manne derives aggregate consumption, investment, energy cost, and gross output. The no-nuclear policy has a relatively small macroeconomic effect. The loss in GNP (consumption plus investment) in 2010 is $109 billion or about 3.1% of GNP. By 2020 the loss increases to $135 billion or 3.2% of GNP.

Manne also explores the implications of a lower elasticity of substitution (.15 instead of .25) and the following reductions in the supplies of non-nuclear energy including:

- The upper bound upon coal consumption is reduced to 25 quads in the year 2000 (instead of 40 quads) and to an asymptote of 40 (instead of 50 quads);
- No shale oil resources are developed because of air and water quality limits;
- The introduction date for large-scale direct solar electricity is delayed from the year 2000 to 2020; and
- AES costs are equivalent to oil and gas at $8 instead of $5 per million BTU.

Under these circumstances the economic losses associated with a no-nuclear

policy are enormous. They amount to $331 billion in the year 2000, $586 billion in 2010, and $813 billion in 2020. These losses correspond to reductions of 10%, 15.7%, and 18.4% in GNP, respectively. Unfortunately, Manne does not show results for changes in supply holding the elasticity of substitution constant, so it is impossible to measure the exact impact of supply changes on GNP.

Stanford's PILOT model has also been used to simulate alternative supply scenarios. The scenarios differ from one another primarily in the constraints imposed on coal production and the assumptions made about the availability of oil and gas resources and the cost of mining uranium ore. According to Dantzig, Connolly, and Parikh (1978, p. 5-6), "The per capita consumption...rises an average of 1.7% per year in the base case....In the high energy availability scenario, it rises faster and attains a 17% higher consumption level by 2010. In the low availability scenario...it rises slower and attains 28% lower consumption levels by 2010 than the base case." The comparative per capita consumption figures generated by the PILOT model can be summarized as follows:

SCENARIO (Constant 1967 Dollars)

Year	Low Availability	Base Case	High Availability
1980	$3093	$3005	$2989
1990	3701	4628	4750
2000	3701	5155	5710
2010	3701	5155	6023

Judging from the PILOT simulations, the availability of energy has a tremendous impact on per capita consumption. But it must be remembered that the PILOT model allows for virtually no substitution between primary energy and other economic inputs. Hogan reports a very low elasticity of

substitution for PILOT of .10. Therefore, the PILOT results may simply mirror the extremely rigid structure of the model.

Capital Investment

Since the energy sector is capital intensive, changes in energy supply often imply substantial changes in capital investment. The Bechtel energy supply planning model provides estimates of the total direct capital needed to bring a variety of energy supply and transportation facilities on-line.

Carasso, et al. (1974, 1975) generate a variety of energy supply scenarios with the Bechtel model. One of these scenarios depicts the President's energy program (as described in the "Draft Environmental Impact Statement of the Energy Independence Act of 1975," March 1975, Federal Energy Administration). The President's program targeted major increases in the production of coal and nuclear fuels, modest increases in oil, hydro electric power, and geothermal power, and a decline in natural gas. Moreover, the program provided for an annual growth rate of 6.5% in electric generation capacity.

The Bechtel group reports that the ten-year (1976-1985) cumulative capital requirements for implementing the President's program amount to $559 billion. Electric utilities account for 74% of this total investment in the energy industry. Annual requirements increase from $33.6 billion in 1974 to a peak of $62.4 billion in 1983. To put these energy capital requirements into perspective, total investment in the U.S. in 1975 only amounted to $100 billion.

ENERGY SHORTAGES

So far the discussion has focused on the long-term impact of gradual changes in energy availability. But the very term "energy crisis" invokes images of sudden supply cutbacks with serious short-term consequences. (For a survey of people's widely varying conceptions of the U.S. energy crisis, see Gottlieb and Matre (1976a, 1976b)). Nordhaus (1974a) defines a crisis as a market displaying either very sharp increases in price or a quantitative restriction. Nordhaus goes on to say that a restriction implies a sharp increase in the effective price, as opposed to the quoted or market price.

By Nordhaus' definition the energy market reached the crisis stage in the fall of 1973 and the winter of 1973-74. Quantity restrictions became especially severe in automotive gasoline, where the short-fall ranged from zero to 30% by state. But the Arab oil embargo, or perhaps the government regulations designed to counter the embargo, also produced supply cutbacks in a variety of petroleum products, ranging from aviation gasoline to petrochemical feedstock.

Some economists predict recurring energy shortages in the future. These shortages can arise for any one or more of the following reasons:

- Short-run stochastic demand fluctuations, e.g., unexpectedly cold winters.
- Stochastic supply shocks, e.g., breakdown of mines, utility plants, pipelines, etc.
- Strategic supply shocks, e.g., strikes by coal miners, OPEC oil embargoes, or cutbacks because of political instability (such as in Iran).
- Overly high capacity utilization rates resulting in frequent excess demand, e.g., gasoline refining during the 1973 oil crisis, electric utility generation and transmission during peak loads.

- Explicit public policy measures which reduce energy supply, e.g., oil import quotas, price regulations on natural gas, reductions in the depletion rate of domestic petroleum, restrictions on the development of nuclear energy, and strict environmental constraints on coal utilization.

Economic Output

Energy shortages, both past and prospective, have received intense coverage by the national news media. But scholars have paid scant attention to these same shortages, perhaps because of the complexity of the topic. Manove (1973) provides one of the few conceptual analyses of the impact of shortages. He uses an input-output model to portray the workings of a multi-sector (industry) economy. In such a model the input coefficients, a_{ij}, play a key role in determining the impact of a shortage. Since a_{ij} measures the amount of sector i output used to produce one unit of sector j output, the inverse of a_{ij} $(1/a_{ij})$ can be viewed as a productivity coefficient. Manove argues that in the event of a shortage, oil (or any other good) could be allocated to the sectors where it is most productive (highest productivity coefficients), thereby mitigating the adverse effects on output.

The indirect impacts of a shortage can also be reduced by allocating oil to basic industries instead of cutting it from the industries providing goods for final demand. Manove proposes a formal procedure for minimizing the impact of a shortage on aggregate output (for some possible shortcomings in this procedure see Murrell and Green (1977)).

No one has yet applied the Manove procedure to the study of energy shortages, but Glassey and Benenson (1975a, 1975b) do use an input-output model to measure the direct and indirect impacts of energy shortages (electric generation, petroleum refining, crude petroleum and natural gas,

natural gas and utilities, coal production, and petroleum imports). As a sample of their findings, a reduction in refined petroleum production by 10% has almost no impact on GNP. Further reductions produce a substantial loss in GNP. Indeed, an additional 7% decline hammers GNP down by 22%.

Penn, et al. (1976) and Penn and Irwin (1977) also use an input-output model to study the short-run economic effects of reduced energy availability. Penn, et al. (1976) report the results from four different supply situations: (1) a 2% reduction in domestic coal supply, (2) a 1.0 million and (3) a 1.5 million barrel per day reduction in crude petroleum imports, and (4) a 10% reduction in natural gas supplies. The second and third supply situations correspond to a partial embargo; the fourth, to a winter gas shortage. Supply interruptions in petroleum reduce gross output by 4 to 6%. The impact of a reduction in natural gas is even more severe, averaging nearly 8%.

Wharton Econometric Forecasting Associates (undated) also develop a methodology for simulating an oil embargo in an input-output framework, but they provide no empirical results.

Pindyck (1977c) attempts to measure the economic impact of shortages, but with demand and supply analysis rather than with input-output models. Pindyck measures the cost of a natural gas shortage. According to Pindyck (p. 2), "The direct cause of this shortage has been price regulation by the Federal Power Commission." The artificially low gas prices mandated by the FPC stimulated demand while at the same time suppressing supplies. Pindyck believes that there are three components to the cost of a shortage. These components (p. 21) are:

(1) Some consumers are unable to obtain gas. There is thus a direct loss of consumer surplus, measured as the value to these consumers of the gas they otherwise would have purchased.

(2) The shortage of natural gas results in increased demand for other fuels (oil and coal), raising the prices of those fuels to all consumers.

(3) Curtailments of gas result in unemployment and thus lost GNP.

The first cost component, the direct loss in consumer surplus, can be calculated from the demand function for natural gas. Pindyck uses an econometric model of the natural gas industry to estimate the quantities produced at the free market and regulated prices. The consumer surplus losses for the period 1977 to 1985 total $11.8 billion for the FPC rates compared to phased deregulation.

In order to calculate the cost of shortage-induced expenditures, Pindyck assumes that half the excess demand for gas is satisfied by oil and coal and that their long-run elasticities are -.5 and .4 respectively.

Pindyck bases his calculation of lost GNP on estimates prepared by the American Gas Association (1977) on unemployment resulting from natural gas shortages during the winter of 1976-77. The AGA figures are as follows:

Date	Number Unemployed
Jan. 11	0
26	240,000
27	650,000
28	840,000
Feb. 4	1,212,000
8	870,600
12	532,000
18	218,000
26	92,500
Mar. 4	65,400
14	10,000

To put these unemployment figures in perspective, the winter gas shortage caused nationwide curtailments totaling 23% of "firm" requirements, with even more severe shortages in several states. Pindyck estimates the gas shortage at 5.9 trillion cubic feet. Pindyck converts the rate of unemployment into an average increase in the unemployment rate on an annual basis (0.093%). He then assumes that changes in the gas shortage during 1977 to 1985 will cause proportional changes in the increase in the unemployment rate. The consumer surplus losses turn out to be very small in comparison to the shortage-induced expenditures on oil and gas ($83 billion) and the cost of shortage-induced unemployment ($85.9 billion).

Tolley and Wilman (1977) provide the most comprehensive conceptual study of the economic effects of embargoes and of policies for lessening a country's vulnerability to these curtailments. They base their analysis upon a detailed investigation of the benefits and costs of a commodity in the absence of embargoes and of the alterations due to embargoes. In the absence of embargoes, the benefits are measured by the area under the long-run demand curve. The cost of the commodity consists of the cost of domestic production and of imports. The threat of embargoes alters these costs and benefits in the following ways:

- Losses reflected in short-run market demand during an embargo
- External losses in the country during an embargo
- Savings due to reduced imports during an embargo

In the absence of externalities or market restrictions, the possibility of an embargo leads to private adjustments. These adjustments consist of reducing consumption and expanding production, thereby raising the marginal value of consumption less than that of production. However, em-

bargoes may impose externalities such as increased unemployment or adverse changes in foreign-policy outcomes. In this case, private adjustment must be supplemented with a tariff on imports. According to Tolley and Wilman this tariff should be proportional to the degree of foreign dependence (vulnerable imports as a percentage of consumption in the absence of an embargo threat) and inversely proportional to the elasticity of external embargo loss, and should vary directly with the probability of an embargo. Bhagwati and Srinivasan (1976) also explore optimal policy intervention when there is the possibility of a market disruption.

Unlike Tolley and Wilman, Tani and Boyd (1976) provide quantitative estimates of the economic cost of an embargo. They base their measure of the cost of an embargo on net social surplus, the algebraic sum of consumers' and producers' surpluses. Tani and Boyd choose to discard GNP as a measure of the cost of an embargo for two reasons. First, they argue that the loss in GNP overestimates the cost. (Because of the multiplier, it takes much less than a dollar invested in the economy to raise GNP by a dollar.) Second, there is no direct linkage between GNP and societal benefits. Tani and Boyd then go on to show that the cost of the embargo approximately equals the duration of the embargo times the change in price caused by the embargo and times the average quantity of oil consumed before and during the embargo. They conclude that the economic cost to society of the 1973 embargo amounted to $18 billion.

Several studies of the impact of supply cutbacks on economic output have been presented in this section. The authors of these studies all appear to implicitly assume that limited supplies continue to be allo-

cated via the pricing mechanism. In reality, the government almost always falls back on some form of non-price (and often non-economic) rationing during shortages. Willrich (1976) provides a detailed discussion of a variety of techniques for managing energy shortages. And Stauffer and Jensen (1974) explore alternative mechanisms for rationing natural gas. No doubt the actual impact of an energy shortage will depend significantly upon the allocation schemes selected by the government.

Labor

Only John F. Early (1974) provides any direct estimate of the effect of the energy crisis on unemployment. Early attempts to answer the question: "What was the effect of fuel shortages upon the level and composition of employment during the 1973-74 winter?"

Early relies primarily upon a monthly payroll survey of 160,000 establishments by the Bureau of Labor and Statistics to answer this question. One(?) of these surveys asked employees to indicate if an inability to obtain sufficient supplies of fuel, electric power, or petroleum products resulted in reductions in employment or workweek schedules.

Judging from the survey data, the most obvious direct impact of the energy crisis was the effect on gasoline service stations because of closings and/or reduced hours. Early reports that the total net direct job loss caused by energy shortages during the November 1973-March 1974 period was between 150,000 and 225,000.

The energy shortage also had indirect effects on employment. Early defines negative indirect effects as a reduction in the output of goods and services because of "reduced demand arising from potential customers' actual or anticipated inability to obtain sufficient supplies of petroleum

products." Industries bearing the brunt of these negative indirect effects included automobiles and automobile parts, recreational vehicles, and hotels and other lodging places. Early concludes by attributing most of the increased unemployment of 380,000 or 8.9% during November 1973 to March 1974 to energy shortages, particularly of automotive gasoline.

Penn, et al. (1976) and Penn and Irwin (1977) use an input-output model to study the impact of reduced energy availability on employment (and other aggregate economic variables). They report that a 1 to 1.5 million barrel per day cutback in oil causes a 4 to 6% decline in employment. A 10% reduction in natural gas has an even more severe impact -- employment drops by nearly 8%.

The only other study of energy availability and employment is by Kutscher and Bowman (1974). They use input-output analysis to find the amount of refined petroleum used per worker in 1970 by each of 125 U.S. industries. However, they do not investigate the implications of these figures for aggregate employment.

UNCERTAINTY ABOUT ENERGY SUPPLY

None of the large scale energy models explicitly incorporate uncertainty about energy supply. Instead, the model-builders capture the effects of uncertainty by simply generating different scenarios. (See, for example, Boudrye, et al. (1977), Meyer, et al. (1974), M.I.T. Energy Laboratory Policy Study Group (1974), and Dupree and Corsentino (1975).) Stover, Hayward, and Becker (1978) attempt to improve upon this deterministic approach by developing and demonstrating a methodology for incorporating probabilistic considerations into energy supply models. This methodology is called probabilistic system dynamics.

They use two separate mechanisms to introduce uncertainty into a deterministic model of the electric utility industry (ELECTRIC3). The first change involves the incorporation of future events into the model; the second, consideration of the uncertainty associated with the exogenous inputs to the model. A set of eighteen different future events are developed and incorporated into the ELECTRIC3 model. Next the probability of occurrence of each event is determined. Then three kinds of interaction are identified for each event: the impact of the event on the model, the impact of the model on the event probability, and the impacts of the event on other events and in turn their impact on it. Cross-impact analysis is used to calculate the probabilities of interaction between events.

Stover, Hayward, and Becker conclude that the addition of uncertainty to simulation models offers two important advantages. It makes it possible to include future events, thereby freeing the model from the assumption that the future will simply be a reflection of the past. Second, it creates the ability to generate ranges for output variables. This provides for the measurement of uncertainty and the analysis of actions designed to reduce uncertainty. There is still another advantage to explicitly incorporating uncertainty about supply. The best policies in an uncertain environment may be very different from the best policies when all parameters are known. Under uncertainty the best policies may be those that mitigate the effects of extremely costly contingencies which occur only infrequently.

Gilbert and Stiglitz (1978a, 1978b) take a different approach to analyzing the effect of risk on energy supplies. They first present a detailed overview of the economic analysis of uncertainty. This overview

covers the basic concepts of risk-bearing, mechanisms by which firms and individuals share risk, the effect of uncertainty on the actions of the firms, and the value of information. Then they survey the effects of risk on energy supply.

Gilbert and Stiglitz offer several interesting conclusions about the impact of uncertainty on energy supply. They claim that markets fail to provide the correct signals for resource allocation because of the public good and speculative value of information. Also, imperfect market structures (and uncertainty) lead to a definite and downward bias in extraction rates. Finally, uncertainty about policy is potentially more important in the energy sector than in any other sector, because the price of exhaustible resources contains a significant rent element.

CHAPTER III

PRICE OF ENERGY

Higher energy prices have had a dramatic impact on the U.S. economy. According to Hudson and Jorgenson (1978b, p. 2), higher prices not only reduced the growth of energy consumption, but also "resulted in a slowdown in economic growth, a weak recovery of capital spending, a substantial increase in employment and a decline in the growth of productivity."

Hudson and Behling (1978) provide a detailed description of the channels through which higher energy prices affect the economy (and the energy sector). Figure 3-1 illustrates these channels. The immediate result of an increase (or decrease) in energy prices is a change in the structure of relative input prices. Producers respond to this change in cost structure by shifting their factor combinations away from higher priced energy intensive inputs and processes, thereby reducing energy use.

These shifts in producers' demands for energy, capital, labor, and materials cause further changes in relative prices. Adjustments in input prices in turn lead to changes in both the level and pattern of output prices. The overall result of an increase in the price of energy is to make energy intensive goods and services relatively more expensive. Sectors like commercial transportation (and of course, energy output) show the largest increases in prices. Less energy intensive sectors like agriculture and construction display smaller price increases. And the least energy intensive sectors -- services, trade, and communications -- show only small price increases or perhaps even price decreases.

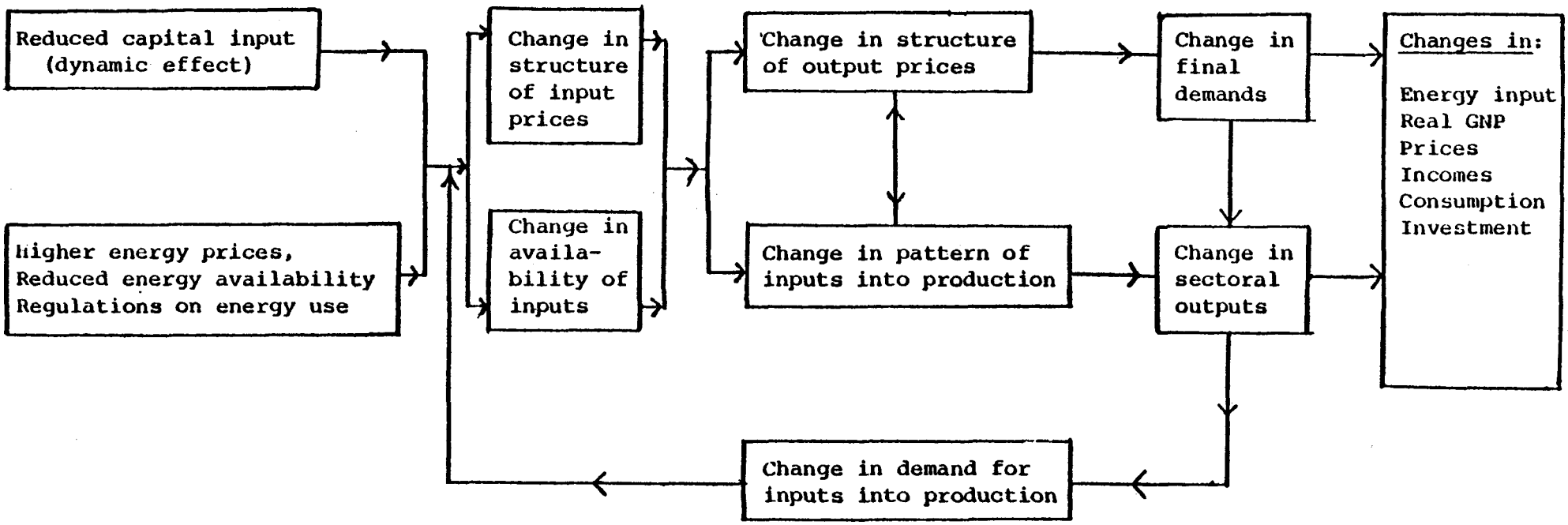


Figure 3-1. Channels through Which Higher Energy Prices Impact the Economy

Source: Hudson and Behling (1978, p. 256).

Final demand -- personal consumption, private investment, government purchases, and exports -- responds to these changes in input prices. The most obvious response is a reduction in the purchases of high priced energy. Energy intensive goods and services also suffer as buyers switch to less costly goods and services. This shift in final demand reinforces changes in the supply side and causes further cutbacks in energy consumption. Higher energy prices also impact capital. But here the effect is much more uncertain and depends upon whether capital and energy are substitutes or complements, an issue examined in detail in later sections of this chapter.

ELASTICITIES OF SUBSTITUTION

To a large extent, the impact of higher energy prices on the economy depends upon the elasticities of substitution between energy and other factors of production. High elasticities imply considerable flexibility in energy utilization and a small impact on the economy. The aggregate elasticity of substitution between energy and all other inputs was discussed in Chapter II. This section extends that analysis to substitution between energy and three general factors of production -- labor, materials, and capital.

Definitions of the Elasticity of Substitution

According to Berndt and Wood (1977b), there are at least three definitions of the elasticity of substitution. All of these definitions bear some resemblance to the more common price elasticity measure, defined as follows:

$$\varepsilon_{ij} = \frac{\partial x_i}{\partial p_j} \frac{p_j}{x_i} = \frac{\partial \ln x_i}{\partial \ln p_j}$$

The x_i are factor inputs and the p_i are factor prices, ln denotes the natural logarithm, and ∂ is the partial derivative. The price elasticity measures the percentage change in quantity of a factor arising from a 1% change in a single factor price (holding all other prices and output constant). Using the Hicks-Allen terminology, two factor inputs x_i and x_j can be defined as substitutes, independent, or complements depending upon whether ε_{ij} is positive, zero, or negative, respectively. When there are only two inputs to the production function, they must be substitutes.

Another measure of the elasticity of substitution, the Allen partial elasticities of substitution, is probably the most relevant to the analysis of energy-economy interactions. These elasticities are defined as follows:

$$\sigma_{ij} = \varepsilon_{ij}/M_j$$

where M_j equals the share of the jth input in total factor cost, i.e.,

$$M_j = p_j x_j / \sum_{i=1}^{n} p_i x_i .$$

An Allen partial elasticity of substitution can be viewed as simply a normalized price elasticity. Like the price elasticity, all inputs are allowed to adjust to their cost-minimizing level (assuming a fixed output) after a price change.

Another frequently used measure of flexibility in resource utilization is the direct elasticity of substitution,

$$d_{ij} = \frac{\partial \ln (x_i/x_j)}{\partial \ln (p_j/p_i)} .$$

The direct elasticity lacks intuitive appeal since it measures the percentage change in x_i/x_j, given a percentage change in p_j/p_i. Moreover, with a direct elasticity, only the two inputs x_i and x_j are allowed to adjust to their optimal levels. By definition, all of the direct elasticities must be greater than the zero. Finally, as Berndt and Wood note (1977b, p. 11), when there are only two inputs, the Allen partial elasticity equals the direct elasticity.

One other measure of substitution is the shadow elasticity of substitution, defined as

$$S_{ij} = \frac{\partial \ln (p_i/p_j)}{\partial \ln (x_j/x_i)}$$

The shadow price elasticity shows the percentage change in the ratio of input prices (p_i/p_j) resulting from a percentage change in the quantity ratio (x_j/x_i) when prices of the other factors and total shadow costs remain fixed.

Review of Elasticities of Substitution

The literature on elasticities of substitution between energy and other factors of production has grown exponentially over the past four or five years. Fortunately, there are several excellent reviews of this literature including Berndt and Wood (1977a) and Pindyck (1977a).

Berndt and Wood begin their review by contrasting two diametrically opposed views of elasticities of substitution. According to them, most early studies of the demand for energy are based upon the assumption of total dependence of energy demand upon GNP, i.e.,

$$\alpha = \frac{\text{Total BTUs}}{\text{Real GNP}}$$

With the total BTUs required to produce a given level of output fixed, forecasts of future energy demand simply involved estimating the constant term and then projecting GNP. A simple variation of this theme involved time-trending the energy-to-GNP ratio. Berndt and Wood point out the well-known fact that the "total dependence" method of projecting energy demands implies that the derived demands for all factors of production are independent of input prices. In other words, there are no substitution possibilities.

Much of the CONAES modeling efforts has been based upon an assumption diametrically opposed to this view -- complete independence between energy demand and GNP growth (see National Research Council (1978)). This produces a wide range of energy demand projections, all consistent with a single projection of GNP, thereby implying that substantial substitution possibilities exist between energy and non-energy factors of production (and among outputs).

Berndt and Wood base their review of empirical studies of the relationship between energy and non-energy inputs upon a KLEM production function. A KLEM production function relates the flow of gross output (Y) to the input services of capital (K), labor (L), energy (E), and other materials (M). They state (p. 9) that the case of total dependence (fixed proportions) can be viewed as:

$$\sigma_{ij} = 0, \qquad i, j = K, L, E, M$$

This equation corresponds to zero substitution between the various inputs. In contrast to total dependence, near independence implies that the σ_{ij} are all positive and very large (especially between energy and other inputs).

Berndt and Wood conclude that a review of empirical results on elasticities of substitution between energy and other factors of production should focus on:

$$\sigma_{Ei} \qquad \text{for any } i \tag{3.1}$$

and on:

$$\sigma_{Ki} = \sigma_{Li} \qquad i = E, M \tag{3.2}$$

$$\sigma_{(KE),i} = \sigma_{K*i} \qquad \text{for any } i \tag{3.3}$$

and the consistency of indexes of value added and utilized capital. Equation (3.1) corresponds to the elasticities of substitution between energy (E) and other factors of production (i). Equation (3.2) expresses necessary conditions for studying the relationship between energy demand and aggregate GNP (value-added). These weak separability conditions imply that the capital-labor ratio does not depend upon the price of energy or materials. The third equation corresponds to weak separability of capital and energy from other factors of production, necessary conditions for the consistency of a utilized capital composite index.

Berndt and Wood (1977a, p. 11) begin by summarizing the findings on separability. According to them, the "results of empirical tests for the validity of the GNP specification are mixed and tend to vary considerably by industry. A general, conclusive finding is not yet available." Berndt and Wood (1975) and Moroney and Toevs (1977) find no evidence of separability. However, the Humphrey and Moroney (1975) and Griffin and Gregory (1976) results support separability.

Berndt and Wood divide their summary of the results of substitution

into two categories: Energy and non-capital inputs, and energy and capital. Most studies report positive cross-elasticities between energy and labor. Therefore, substitution possibilities between these two inputs appear to be present, although somewhat limited. Similar results hold for energy and other materials. The findings on energy-capital substitution possibilities are much more ambiguous. Some report complementarity between these factors, others find substitutability.

Several studies of energy substitution have appeared since the Berndt and Wood review article, including Hudson and Jorgenson (1978a), Kopp and Smith (1978), Pindyck (1977a), Özatalay, Grubaugh, and Long (1978, 1979, undated), and Mork (1978a). The techniques and results of these studies, together with those summarized in Berndt and Wood, are presented in Table 3-1.

Energy and Capital

The relationship between energy and capital is a crucial one for the economy. For that reason, the lack of consensus about the Allen partial elasticities of substitution between these two inputs is reason for concern. Berndt and Wood (1977b) make an important contribution by attempting to reconcile these differences.

They begin their reconciliation by explaining the engineering and econometric approaches to industrial energy conservation and capital formation. According to Berndt and Wood (p. 15),

> Engineering studies tend to focus upon the changes in capital design, and the manner in which capital and energy are jointly utilized. Their emphasis is on the subset of inputs including capital and energy inputs, with the assumption of weak separability between these inputs and the other factors of production. Thus, engineering studies tend to provide information to evaluate gross elasticities of substitution between the inputs comprising a subset of factor inputs.

TABLE 3-1

SUMMARY OF EMPIRICAL FINDINGS ON SUBSTITUTION POSSIBILITIES BETWEEN ENERGY AND NON-ENERGY INPUTS

Study	Data Base	Methodology	Principal Findings
Berndt and Wood (1975)	U.S. manufacturing, 1947-1971	Translog: KLEM. Iterative three-stage least squares	E and K comp. E and L sub. E and M sub.
Fields and Grebenstein (1977)	U.S. manufacturing by state, 1971	NA	E and L sub.
Fuss (1977a)	Canadian manufacturing by region, 1961-1971	Translog: KLEM.	E and L sub. E and M sub.
Griffin and Gregory (1976)	Nine OECD countries manufacturing, 1955, 1960, 1965, and 1969	Translog: KLE. Iterative Zellner efficient procedure	E and K sub. E and L sub.
Hawkins (1977)	Australia by industry, 1949/50 - 1967/68	Hanoch's constant difference elasticity of substitution: land and buildings, plant and machinery, labor, solid fuels, liquid fuels, and electricity. Two-stage least squares	Results show evidence of temporal instability.
Hnyilicza (1975, 1976)	Energy and non-energy sectors of the U.S. economy, 1947-1971	Translog: capital, labor, energy, and non-energy goods (N). Iterative three-stage least squares	For the non-energy sector: E and K ind. E and L ind. E and N sub. For the energy sector: E and K ind. E and L sub. E and N ind.

Study	Data Base	Methodology	Principal Findings
Hudson and Jorgenson (1978a)	U.S. manufacturing (time period not given)	Not described	E and K comp. E and L sub. E and M comp.
	U.S. agriculture, non-fuel mining, and construction		E and K ind. E and L sub. E and M sub.
	Commercial transport		E and K comp. E and L ind. E and M sub.
	Services, trade, and communication		E and K sub. E and L sub. E and M comp.
			Hudson and Jorgenson conclude that over all four sectors, E and K are complements, E and L substitutes, and E and M substitutes.
Humphrey and Moroney (1975)	U.S. manufacturing by industry, 1963	Translog: capital, labor, and natural resources (not energy). Iterative Zellner efficient procedure	N and K sub. N and L sub.
Kopp and Smith (1978)	U.S. manufacturing, 1947-1970	Translog: physical capital, working capital, labor, energy and materials. Iterative Zellner efficient procedure	Physical capital and energy sub. Working capital and energy comp. Physical capital and labor sub. Working capital and labor ind. Physical capital and materials sub. Working capital and materials sub.

Study	Data Base	Methodology	Principal Findings
Mork (1978a)	U.S. economy, quarterly 1949-1975	Non-homothetic generalized Leontief: capital, labor, energy, and agriculture. Non-linear three-stage least squares	E and K comp. E and L sub. E and A mixed results (ind. or comp.)
Moroney and Toevs (1977)	U.S. resource-intensive industries, 1954-1971	Translog: capital, labor, and natural resources. Iterative Zellner efficient procedure	N and K generally sub. N and L generally sub.
Özatalay, Grubaugh, and Long (1978, 1979, undated)	Canada, West Germany, Japan, Netherlands, Norway, Sweden, U.S., 1963-1974	Translog: KLEM. A full information maximum likelihood procedure	E and K sub. E and L sub. (only in the long run) E and M ind.
Pindyck (1977a)	Ten OECD countries manufacturing, 1959-1974 (or 1973)	Translog: KLE. Iterative Zellner efficient procedure	E and K sub. E and L sub.
Tintner, Deutsch, Rieder, and Rösner (1977)	Austrian economy, 1955-1972	Cobb-Douglas: capital, labor, and energy. Ordinary least squares	E and L sub. (by definition)

Note: K-capital, L-labor, E-energy, M-material, sub.-substitutes, ind.-independent, comp.-complements.
Factors of production were classified as independent if the elasticity of substitution had an absolute value close to zero, i.e., less than .1.

In contrast to engineering studies, the econometric studies explore the relationship between all inputs, not just energy and capital. Berndt and Wood (p. 15) note that, "Econometric studies, on the other hand, have tended to focus on the relations between all inputs, employing the assumption of weak separability to reduce the number of subsets to a manageable number."

The engineering literature contains numerous examples showing how redesigning or retrofitting equipment and appliances reduces energy use. However, Berndt and Wood argue that the tradeoff between higher initial cost and reduced energy consumption does not necessarily imply a tradeoff between the flow of capital services and the quantity of energy. They demonstrate this point by separating the substitution process into two stages:

- Substitution within the energy-capital composite (called utilized capital by Berndt and Wood).
- Substitution between the energy-capital composite and other inputs.

Substitution within the energy-capital composite is measured by the "gross-price elasticity." By definition, the gross-price elasticity must be positive. Substitution between the energy-capital composite and other economic inputs is measured by the scale elasticity. The sign of this scale elasticity can be positive or negative (or, of course, zero). The price elasticity of energy is equal to the weighted average of these two elasticities.

Berndt and Wood equate the standard engineering literature on capital-energy tradeoffs to changes within the energy-capital composite. For example, an increase in the price of energy causes homeowners to add insulation to their homes to save energy. Therefore, energy and capital can

be viewed as substitutes in terms of gross-price elasticity. However, if the energy price increases, it seems quite likely that producers will substitute labor and materials for the now more expensive energy-capital composite, i.e., the energy-capital composite is complementary to labor and materials. If this scale complementarity dominates, then the price elasticity of capital with respect to energy is negative, i.e., capital and energy are complements.

The Berndt-Wood paradigm goes a long way toward reconciling the conflicting findings on energy and capital substitution. Berndt and Wood also offer several other explanations for these disparate results. They note that almost all the econometric evidence comes from data which do not include the dramatic post-1973 price increases. Second, there is the possibility that the estimates based on annual time-series data reflect short-run variations in capacity utilization rather than the true long-run relationship. Third, there are a number of data problems associated with several of the econometric studies.

For example, both the Griffin and Gregory (1976) and Pindyck (1977a) findings of energy-capital substitutability are based upon international pooled cross-section time series data. But Griffin and Gregory and Pindyck were unable to account for variations in effective tax rates across the OECD countries and over time. Moreover, they both computed the value of capital services as value added minus the wage bill. According to Berndt (1977a, p. 51), this procedure can be criticized on the basis that the resulting residual captures "not only the return to capital equipment and structures, but also the returns to land, inventories, economic rent, working capital, and any errors in the measurement of value added or wage

bill." Moreover, Berndt (1976) shows that elasticity estimates are very sensitive to these data errors and to the choice of the rate of return. Field and Grebenstein (1977) obtain energy-capital substitutability with the value added definition and energy-capital complementarity with a plant and equipment measure of the capital rental price.

Finally, it must be emphasized that this discussion focuses solely on the effect of price on the utilization of factor inputs. All the elasticity measures discussed here are based upon the assumption that total output remains unchanged. However, Hogan (1977a) argues that the assumptions behind the Allen partial elasticities of substitution, i.e., fixed output and prices of other factors, may be inappropriate in a measure of the long-run impact of energy price increases. He argues that an alternative set of assumptions (exogenously given labor supply and a fixed long-run equilibrium real return on capital) is more sensible. In this case higher real energy costs reduce the long-run capital stock so that in this sense, energy and capital are complements.

ECONOMIC OUTPUT

Jorgenson (1978), Hudson and Jorgenson (1978a, 1978b), and Goettle, Hudson, and Lukachinski (1978) provide the most detailed description of the mechanisms by which energy prices influence output. A rise in energy prices leads to a reduction in GNP for two reasons -- changes in input productivity, and a slowing in the rate of capital formation.

After the rise in energy prices, producers attempt to economize by substituting other inputs for energy. But the imperfect substitutability of these alternatives adversely affects the production process and reduces

output. Moreover, the factor inputs replacing energy must be shifted away from other productive activities, causing a further slowing in the growth of output.

Since energy and capital are assumed to be complements, increases in the price of energy also reduce the demand for capital services. This reduction in the demand for capital depresses the rate of return on capital. At lower returns savings and investment become less attractive, so the rate of capital formation slows. This reduction in the rate of capital formation is reinforced by the negative impact on savings and investment of higher energy prices and lower GNP.

Hudson and Jorgenson (1978a, 1978b), Goettle, Hudson, and Lukachinski (1978), JRB Associates (1978), and Duggal, Klein, and Schink (undated) have all recently attempted to measure the impact of higher energy prices on the economy. Goettle, et al. examine three alternative energy price-policy futures with the BNL/DJA model system. This system consists of the Brookhaven National Laboratory (BNL) BESOM model and the Dale Jorgenson Associates Long-Term Interindustry Transactions model.

The Goettle, Hudson, and Lukachinski effort begins with three different sets of energy supply prices specified by the Department of Energy. In order to provide some perspective on these assumptions, they compute primary energy price as a quantity weighted average of coal, oil, gas and uranium. The 1985 medium case differs from the low case by only 1.7%, whereas the high case comes in at 17.6% more than the low case. By the year 2000 the average price of energy differs by 35.9% from the low to the medium case and by 80.4% from the low to the high case.

Judging from these simulations, real GNP declines as a result of the higher energy prices and the ensuing economic adjustments. According to Goettle, Hudson, and Lukachinski, the reductions are moderate in terms of proportions--GNP in the high energy price case is 6% below that of the low price case. And the average annual growth rates of real GNP between 1977 and 2000 are 3.24%, 3.10%, and 2.96% in the low, medium, and high price cases.

Goettle, et al. contrast their findings to those of JRB Associates. JRB uses the DRI quarterly economic model to investigate the impact of higher energy prices. According to Goettle, et al., the response of GNP to higher energy prices in the BNL/DJA system is always greater than in the DRI model. Table 3-2 compares the BNL/DJA and DRI model results in terms of changes in the present value of future real GNP. The GNP changes in the BNL/DJA model are approximately twice those of the DRI model. This conclusion is supported by a comparison of the price elasticity of output from the two models. The GNP/supply price elasticities are about -.10 in the BNL/DJA model and about -.05 in the DRI model.

Why the differences between these two large scale models? Goettle, et al. believe the DRI model underestimates the impact of energy price changes because it contains no supply constraints. As a result, the DRI model only reflects demand adjustments whereas the BNL/DJA system captures the impacts of price changes on both the demand and supply sides.

Duggal, Klein, and Schink (undated) also examine the impact of changes in energy prices. They use the Wharton Annual Energy Model to simulate the effects of a 50¢ per million BTU tax on primary energy consumption with 65% of energy tax collections rebated to the public. Duggal, et al. do not

TABLE 3-2

CHANGES IN THE PRESENT VALUE OF FUTURE REAL GNP LEVELS FROM 1977 TO 1995: A COMPARISON OF BNL/DJA AND DRI MODEL RESULTS (BILLIONS OF 1972 DOLLARS)

BNL/DJA	Medium-Low	High-Medium	High-Low
Discount Rate:			
0 %	-372.44	-458.90	-831.34
6 %	-153.40	-211.53	-364.93
12 %	-68.56	-108.22	-176.78
DRI			
Discount Rate:			
0 %	-181.10	-282.20	-463.30
6 %	-72.55	-126.48	-199.03
12 %	-31.19	-61.46	-92.65

Source: Goettle, Hudson, and Lukachinski (1978, p. 66).

calculate the percentage increase in the average price of energy corresponding to this tax. They do show the percentage changes in the price of oil, natural gas and coal. Judging from these figures the tax amounts to about a 38% increase in the 1979 price of primary energy. As energy prices increase over the years this tax decreases as a percent of the energy price to about 25% in 1990. These price increases are similar in magnitude to those studied by Goettle, et al. and JRB. However, Duggal, et al. find almost no impact from this tax-induced price increase. Real GNP is about $12 billion lower in 1990 and the growth rate in GNP declines from 3.1% to 3.0%. If the CPI is adjusted for the tax rebate, the economy actually performs better with the tax. Real GNP in the CPI adjusted tax case exceeds base line GNP by $49 billion and the growth rate is .2% higher.

OTHER ENERGY-ECONOMY INTERACTIONS

The empirical research to date indicates that labor and materials are substitutes for energy. The evidence on the relationship between energy and capital is mixed, but Berndt and Wood (1977b), and Hogan (1977a) have both argued convincingly that energy and capital are complements (but in different contexts).

Jorgenson (1978) uses these empirical relationships to analyze the impact of higher energy prices. Here are the various short-run impacts Jorgenson sees:

- Increased demand for labor. As a result wage rates rise and employment increases. At the same time higher wage rates and improved employment prospects create a larger labor force and continued high levels of unemployment. In addition, personal disposable income probably increases.

- Decreased demand for capital. With the stock of capital fixed in the short run, rates of return drop, causing investment to decline and consumption to increase.

- Increased demand for materials.

In the long run, Jorgenson believes the reduction in the level of capital formation will slow the rate of substitution of capital for labor. This slows the rate of productivity growth and in turn lowers the rate of economic growth. With the slowdown in economic growth comes disappointing gains in real personal disposable income and an end to the boom in consumer spending. Jorgenson concludes that the "Golden Age" is behind the U.S.

Hudson and Jorgenson (1974, 1976a, 1976b, 1978a) and Hudson and Behling (1978) all report the impact of different government policies on the economy. Because a variety of tax, price, and conservation measures are lumped together, it is impossible to assign specific impacts to changes in energy prices. However, Goettle, Hudson, and Lukachinski (1978) do isolate the impact of energy prices on real GNP and its components. The Goettle, Hudson, and Lukachinski methodology was discussed in the preceding section. Their results for consumption, investment, government, net exports, and the price of GNP are presented in Table 3-3. Perhaps one of the most conspicuous features of this table is the negligible impact of higher energy prices on the overall price level.

Table 3-3 also shows that higher energy prices depress investment only slightly at first. But as the years go by, the negative influence grows greater, reducing investment by about 10% in the year 2000. These results argue strongly against fears of a capital "gap" caused by the energy crisis. If Goettle, Hudson, and Lukachinski are right, the increased capital requirements of the energy sector can probably be accommodated by reduced investment in the rest of the economy.

TABLE 3-3

ENERGY PRICE IMPACTS ON GNP AND ITS COMPONENTS
(Billions of 1972 dollars)

1985	Low	Medium	High
GNP	1779.4	1776.5	1757.4
Consumption	1149.8	1146.1	1129.9
Investment	264.7	264.6	262.7
Government	344.6	344.6	344.6
Net Exports	20.2	21.1	20.1
GNP Price (1972=100)	2.0177	2.0158	2.0198
1990			
GNP	2075.6	2039.3	2003.3
Consumption	1351.2	1322.8	1292.9
Investment	304.6	299.2	293.5
Government	408.0	408.0	408.0
Net Exports	11.8	9.2	8.9
GNP Price (1972=100)	2.4291	2.4300	2.4341
2000			
GNP	2785.8	2696.3	2617.7
Consumption	1806.8	1737.5	1680.6
Investment	408.0	388.3	367.4
Government	567.0	567.0	567.0
Net Exports	4.1	3.5	2.8
GNP Price (1972=100)	3.5554	3.5603	3.5962

Source: Goettle, Hudson, and Lukachinski (1978, p. 39).

Other studies also examine the effect of higher energy prices on investment, the capital stock, capital productivity, etc. Jack Faucett Associates (1976) projects the impact of changes in energy prices on investment in the energy-consuming sectors during 1975 to 1985. These projections primarily reflect investment associated with conservation efforts (retrofitting existing equipment and substituting more energy efficient equipment) and with fuel substitution (largely coal for oil and gas in large industrial boiler installations). Faucett puts the total amount of this direct energy related investment at $20-44 billion during the next decade.

Rasche and Tatom (1977a, 1977b) focus on the impact of higher energy prices on the existing stock of capital rather than on investment. They believe that the jump in energy prices during 1974 (the wholesale price of energy increased by 45.3%) reduced manufacturing capacity and potential GNP by 4 to 5%.

Myers (1977) also sees higher energy prices exerting a decidedly negative impact on capital by speeding up obsolescence. Myers summarizes results showing that the plant and equipment of an industry are made up of a series of "vintages," with each vintage corresponding to a different year of construction. These vintages differ in terms of the productivity of factor inputs, especially energy. As a result, higher energy costs fall more heavily on the older plant and equipment, reducing profits and causing earlier retirements of this capital stock. Gunning and Waelbroeck (1975) study investment and scrappage in a putty-clay world (substitution between energy and capital is only possible ex ante).

These price impacts on capital investment, and the possibility of a complementary relationship between capital and energy, raise serious

questions about a number of energy conservation policies. Boshier (1978) points out that, based on the empirical evidence on substitution between energy and non-energy inputs, the investment tax credit and the accelerated depreciation provisions increase the demand for capital and for energy. Berndt and Wood (1977c, p. 33) conclude that "arguments alleging that additional investment incentives will promote energy conservation goals" appear unconvincing. Indeed, Berndt and Wood's analysis "suggests these policies will actually exacerbate energy demand...." Chapman (1977) argues that present tax policy distorts factor prices by lowering capital costs and raising labor costs. This tax policy stimulates capital investment and restrains both energy conservation and employment. Finally, Hannon (1975) argues that energy conservation programs based on diverting personal consumption dollars to Federal spending or investment spending might very well increase energy consumption, once the indirect effects are considered.

Another issue of great importance associated with energy prices concerns productivity. According to Denison (1978), American productivity (measured by national income per person employed -- NIPPE) showed a puzzling drop during 1974 and 1975. This sharp and unusual decline in NIPPE amounted to -4.9% in 1974 and -.7% in 1975. Although Denison rejects the sudden rise in energy prices during that year as an explanation for this drop, the timing of the price rise and the drop in productivity may be more than coincidental. Berndt and Kahled (1977) present a model of production behavior that can be used to estimate total factor productivity during the time period in question (but is not).

PROPERTIES OF ENERGY PRICES

Despite the importance of energy prices to the economy, nothing has yet been said about their determination. Most energy comes from exhaustible resources. Solow (1974) notes that Harold Hotelling (1931) had provided a theoretical explanation of the time path of exhaustible resource prices as early as 1931. Hotelling shows that in a competitive equilibrium the net value of a resource deposit like a pool of oil must grow at a rate equal to the rate of interest. The value of a deposit equals the present value of net cash flows (market price minus extraction costs) generated by a deposit. Since a deposit in the ground pays no dividends, the return on a deposit which is left unextracted must consist solely of capital gains.

This fundamental principle of the economics of exhaustible resources guides the determination of long-term energy prices in perfect markets. This energy price consists of two components: a scarcity rent and the extraction cost. The market price of energy can fall or stay constant while the scarcity rent rises, depending upon the behavior of extraction costs.

Nordhaus (1973) applies this analysis to energy resources and introduces the idea of a "backstop" technology. A backstop technology provides an inexhaustible resource base (solar energy, for example) at a relatively high cost. This backstop technology places a ceiling on the market price of energy. Moreover, since there is no scarcity rent associated with it, the backstop technology becomes cost-effective as soon as the market price rises enough to cover the cost. Nordhaus computes the scarcity rents of multiple energy resources using linear programming to solve a cost minimization problem. He notes that the computed prices are much lower than current world prices, implying that competitive theory is not appropriate.

A study of actual energy prices is complicated by the existence of numerous wedges between price and cost. These wedges include monopoly rents, BTU or consumption taxes, import tariffs, price controls, and average cost pricing (rolling in high-priced with low-priced energy). A number of authors comment on these features of energy prices including Bullard, Hannon, and Segal (1976), Laffer (1977), Smith (1978), and Mead (1978).

Sander (1976) reviews the evolution of energy prices. Curiously enough, fears of an energy shortage in the early 1920s provided the initial impetus for two major tax preferences the oil industry enjoyed for the next fifty years -- percentage depletion and the expensing of intangibles. These tax policies attracted an enormous amount of capital to the energy sector and at first reduced oil prices. However, these very same incentives helped to create excess capacity and eventually led to the cartelization of the industry and the adoption of state production controls (prorationing) and import quotas.

Natural gas suffered a worse fate than oil. Its dependence upon interstate pipelines made it an obvious candidate for Federal regulation. With this regulation came a two-tier pricing system and a ceiling on gas prices. As a result, gas prices were held substantially below their incremental cost.

Electricity prices also differ substantially from marginal cost. With electricity prices declining during the 1950s and 1960s because of technological advances and economies of scale, consumers seldom questioned the utility rate-making process. Almost without exception this rate-making process bases prices upon fully allocated costs rather than incremental costs.

These wedges between the price and cost of energy have important implications for energy-economy interactions. However, they are better explored in a microeconomic context rather than in the present survey.

CHAPTER IV

WORLD PRICE OF OIL

Of all the key energy variables affecting the economy, the world price of oil has probably received the most publicity. Ever since the embargo of 1973, the OPEC countries have collectively dictated the world oil price. Marshalla (1977), Cremer and Weitzman (1976), Pindyck (1976, 1978), Adelman (1975), Levy and Sarnat (1975), Ezzati (1976), Schmalensee (1976), Ben-Shabar (1976), and Eckbo (1976) have studied OPEC's price-setting behavior. While there remains considerable uncertainty about the exact nature of this price-setting behavior, no one can deny the effectiveness of the world's newest cartel. Prior to the Arab oil embargo, oil sold for $2.70 a barrel. A year later a barrel fetched $10.47 (see Yager and Steinberg in Fried and Schultze (1975)).

ECONOMIC OUTPUT

The energy crisis imposed substantial costs on the U.S. economy. According to Serot (1978, p. 20), the crisis depressed the economy in three ways. "First, the fourfold rise in oil prices caused inflationary pressures that reduced real income, real personal consumption expenditures, and real investment. Second, the embargo created a psychological climate of uncertainty that further retarded aggregate demand .... Third, the crisis played a major role in misleading policy-makers by focusing their attention away from the underlying weakness of the economy."

Corden (1976, 1977) and Corden and Oppenheimer (1976) provide an excellent conceptual analysis of the world's adjustment to the oil-price rise. The OPEC price rise caused three types of income redistribution.

The primary income-distribution effect was a transfer of income from the rest of the world to OPEC. This was essentially equivalent to the effect of an excise tax on consumers of oil. Secondary and tertiary income-distribution effects also produced a redistribution of income among the non-OPEC countries. These secondary and tertiary effects arose from shifts in the prices of substitutes and complements for OPEC oil and from changed spending patterns.

According to Corden (1977), the oil price rise not only resulted in a redistribution of income, it also caused world income to fall. With higher oil prices, consumers economize on energy. As a result, OPEC producers lose rent on foregone oil output, the governments of non-OPEC countries lose tax revenue, and consumers use income at the margin for less desirable alternatives than energy. In addition, more expensive energy substitutes replace OPEC oil at the margin, resulting in a very significant waste of resources.

Morici (1978) also notes that the increase in the real price of world oil had the same impact as an excise tax imposed on imports of crude oil. Therefore, the net welfare loss and the reduction in GNP caused by the higher energy prices can be examined with the same supply and demand framework used to evaluate the impact of a tariff.

Sweeney (1978) provides a detailed analysis of the impacts of an oil import price change on the economy. He uses six very general equations to represent the economy. Sweeney first assumes that the demand for energy can be described by a constant elasticity demand function for energy. Then he shows that the impact on net national product is greater the larger the initial value share of energy in the economy and the smaller the elasticity of demand for energy.

Figure 4-1 is taken from Sweeney. It shows that increases in the price of world oil always reduce NNP. The actual change depends greatly upon the elasticity of demand. But even with relatively high elasticities, an increase in oil prices can lead to large reductions in NNP. A quadrupling of prices depresses NNP by 12% if the elasticity of demand equals .1 and by 7% if the elasticity equals .7.

Sweeney's conclusions only apply when there is no domestic production of oil. Increased domestic production reduces imports and mitigates the impact on the economy of a higher world oil price, at least in terms of GNP. However, this increased domestic production raises the question of how well GNP measures welfare. Stiglitz (1974) argues that the loss of wealth resulting from the depletion of domestic oil reserves should be included in the measure of national income. The GNP figures instead imply that there is no cost (reduction in GNP) associated with depleting the stock of domestic oil. Moreover, attempts to increase domestic production may permanently damage oil reservoirs, thereby reducing the amount of oil available for future extraction.

Izzo and Spaventa (1973) also analyze the effects of a rise in the world price of oil on economic activity. They conclude that the fall of real income is greater, the higher the ratio of the value of oil imports to the value of autonomous expenditures. The deflationary effects are caused by a decrease in the multiplier: As the prices of imports rise so do the leakages in the process of income creation.

Both Sweeney and Izzo and Spaventa concentrate exclusively on changes in levels of GNP as opposed to growth in GNP. Gunning, Osterrieth, and Waelbroeck (1976) make a significant contribution to the literature on

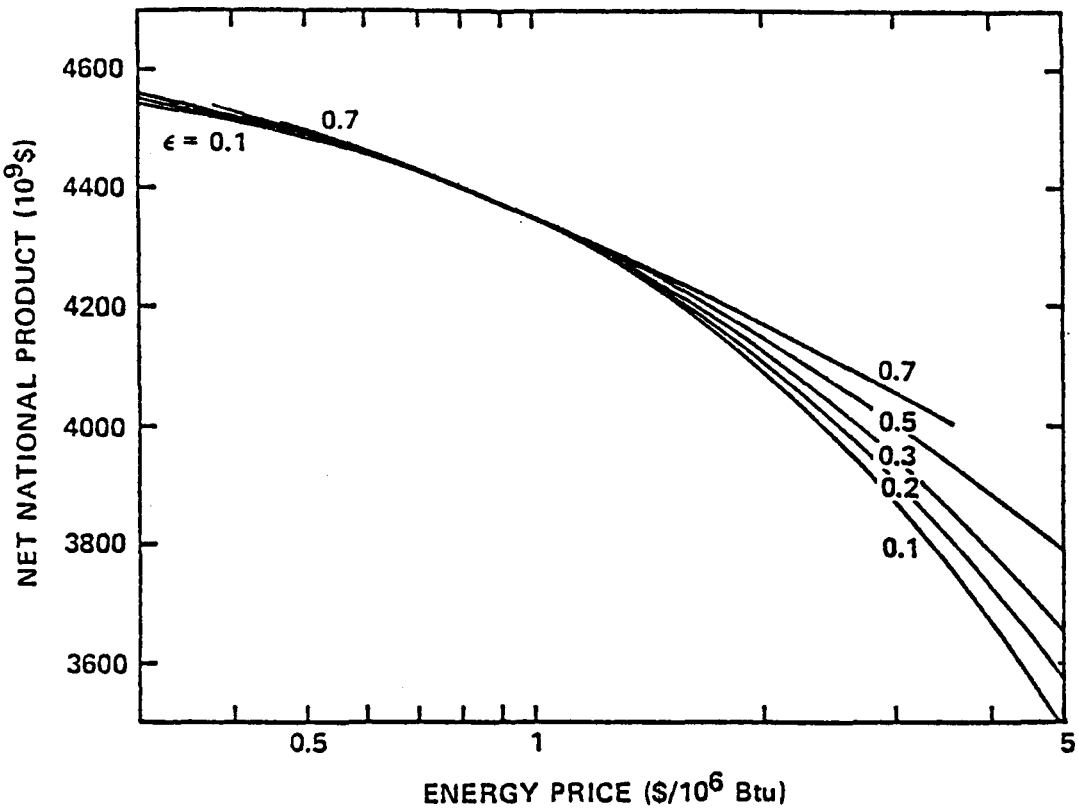


Figure 4-1. Impact of Higher World Oil Prices on Net National Product

Source: Sweeney (1978, p. 10).

energy-economy interactions by assessing the impact of oil price rises on both the level and growth in GNP. They develop a simple but elegant mathematical model to explore these impacts. The model consists of equations describing the following relationships: commodity balance, price determination, production function, investment in capital, profit maximization by producers, and the balance of payments. These equations form the basis for the SIMRICH-OECD model (SIMRICH stands for Simulation of an International Model for Research on the Indirect Consequences of Higher Oil and Energy Prices on the developed world). Gunning, et al. simulate the OECD model under two different price assumptions: oil priced at $3.21 a barrel (1973 price) and at $8.19 a barrel (the early 1975 price in 1973 dollars). The results indicate that the impact on the growth of OECD countries is small--an annual growth rate of 4.21% between 1973-1980 and of 4.37% between 1980 and 1985 compared to growth rates at lower oil prices of 4.37% from 1973-1980 and 4.43% for 1980-1985. Of course, small growth rates in large numbers like GNP can still amount to many billions of dollars. For example, higher oil prices reduce real national income by $41 billion in 1980 and by $61 billion in 1985.

The SIMRICH-OECD model was specifically designed to explore the relationship between the price of energy and potential economic growth. Other more general models have also been used to document these interactions. The findings are reported in Gordon (1975), Fair (1978), Mork and Hall (1978), Basevi (1975), Watanabe (1975), Perry (1975), Serot (1978), Farman-Lagace (1978), Askin (1978b), Pierce and Enzler (1974), etc.

PRICE LEVEL

Unlike their brethren in the physical sciences, economists can seldom subject their hypotheses to controlled experimentation. The 1973 oil embargo provides one of the few exceptions to this rule, albeit at a very high cost. Spot oil prices jumped by nearly 300% in the month following the embargo, going from $3.65 a barrel to about $10. The most obvious consequence of this price shock to the world's economies was a rise in the price level. Although few people will debate this conclusion, many will argue about the exact causes of the inflation, or so it appears from the general comments at an NBER Workshop on "Commodity Prices, Energy, and Inflation" (see Brainard and Cooper (1975)).

The general topic of this workshop was exogenous changes in real prices, with the oil price increase a prime example of this genre of economic phenomena. Do changes in relative prices cause inflation? Judging from the conference proceedings, there are at least two schools of thought on this topic. "Monetarists" discount the role of all relative price changes. Johnson (1977) states this view quite clearly. According to Johnson (p. 12), "It is quite wrong ... to regard the increase in oil prices as inflationary in itself, without supporting argument and supplementary assumptions." Johnson goes on to say that the main effect of higher oil prices is a redistribution of real income (from oil importers to oil exporters), <u>not</u> a monetary effect. Inflationary effects only come into the picture to the extent that the governments of oil importing countries finance the extra cost of consumption through inflationary policies.

"Structuralists," on the other hand, argue that increases in relative prices create an inflationary spiral. For example, Freedman (1975) talks

about higher prices for oil introducing another very powerful thrust to the price spiral. Higher oil costs substantially impact the transportation sector and petrochemical products and these higher costs are passed on to consumers. Moreover, union negotiators increasingly seek contracts incorporating escalator clauses and other forms of income protection. Pollack (1974) too feels that higher oil prices will spark demands for higher wages by workers attempting to keep up with inflation. Pollack also sees other inflationary pressures, including an increase in international reserves, an increase in the economic militancy of other commodity producing nations, and, because of price stickiness, an increased need for price increases in the adjustment process. Finally, Pierce and Enzler (1974, p. 17) note that "The surge in import prices will make the goods that workers buy more expensive, putting pressure on wages, and in turn tending to raise domestic prices."

These differences in opinion can be studied in terms of the CPI or the GNP deflator. The exact impact of a change in the world price of oil depends upon how this price change affects the prices of other products (and in reality, quantities).

The simplest approach is to view the prices of other products as fixed, so that the change in the price level equals

$$\frac{\Sigma\, p_i^1 q_i^0 - \Sigma\, p_i^0 q_i^0}{\Sigma\, p_i^0 q_i^0} = \frac{(p_E^1 - p_E^0)}{p_E^0} \cdot \frac{p_E^0 q_E^0}{\Sigma\, p_i^0 q_i^0}$$

where p_i^0 and q_i^0 are the base-period prices and quantities, p_i^1 are the prices after the oil price rise, p_E^0 and q_E^0 are the pre-embargo oil price and

quantity, and p_E^1 is the post-embargo oil price. In this case, the impact of an oil price increase equals the percentage change in the oil price times the value share of oil imports to total GNP. A one hundred percent increase in the price of oil pushes the CPI or the GNP deflator up by four percent (since oil imports prior to the embargo amounted to about 4% of GNP). Merklein (1974, 1975) bases his calculations of the inflationary impact of the oil price increase on exactly this assumption. He concludes that the impact on the U.S. GNP deflator only amounted to 2.4%. Valdepenas (1974) also takes this approach in estimating the impact of the oil price increase on the Philippine price level. Perry (1974) uses input-output analysis to study the impact of different increases in the prices of natural gas and crude oil in the U.S. on sectoral prices and the overall price level.

Most economists reject this partial equilibrium approach to inflation and instead emphasize the impact of a price increase in any one commodity on the prices of other goods. Monetarists argue that if the money supply remains unchanged, the prices of other goods must decline, thereby negating the impact of the price increase. Structuralists, on the other hand, stress the stickiness of prices (in the downward direction) and the positive linkages between different prices, perhaps implicitly assuming an accommodative monetary policy.

Tests of these competing hypotheses are complicated by the fact that changes in relative prices and changes in exogenous nominal variables (wage rates, exchange rates, money supply) often move together. As a result, there is no easy answer to how much the embargo related increase in the world oil price added to the price-level. Answers range from 1.5% to

8% or more. Pollack (1974) estimates the total impact on U.S. prices to be 3%; Freedman (1975) thinks that the increase pushed prices up in the OECD countries by 3 to 4%. A number of researchers despair of reaching a correct answer by simple analysis and turn instead to large models of the economy.

Pierce and Enzler (1974) published one of the first computer simulation studies of the impact of the world oil price increase on the overall price level. They use a modified version of the MIT-PENN-SSRC quarterly econometric model to capture the price interactions. One of the two shocks studied by Pierce and Enzler corresponds to the increase in the world oil price from $3.50 to about $10 a barrel following the oil embargo. Assuming that the domestic oil price increases to $6.30 a barrel, the deflator for nondurables and services increases by 3%. However, given Pierce and Enzler's initial assumption of no change in the growth of the money supply, the rate of inflation eventually returns to its original level. Pierce and Enzler also examine the impact of the price increase when monetary authorities expand the money stock in proportion to the increase in transactions demand. This expansion in the money stock allows the wage price spiral to continue to a much greater extent. The average annual inflation rate over the seven-year period is 0.7% higher than in the case of no accommodative change.

The Federal Energy Administration (FEA) has also conducted a number of price impact studies, but with the DRI and Wharton models. Askin (1978b) summarizes the results of simulation studies by Malloy (1978) and Farman-Lagace (1978). The 1985 price levels differ from the reference scenarios by as much as 7% with the long-term Wharton model and by 9% with the DRI

model. The scenarios studied in the simulations focus on three different world oil prices ($8, $13, and $16) and five different governmental policies corresponding to the government's response to the energy crisis (no change, increased conservation, increased supply, increased supply and increased conservation, and decreased supply). In the reference case (no change in government policies) a doubling of the world oil price from $8 to $16 raises the GNP implicit price deflator by 4% in the Wharton model and by 9% in the DRI model. It is interesting to note that a government policy of actively expanding supply and inducing conservation holds the change in the GNP deflator to less than 1% in the Wharton model but has almost no impact in the DRI model. So depending on the model used, radically different conclusions can be reached about the severity of the inflation and the impact of government policies. Askin also reports results from modifications of the Malloy and Farman-Lagace simulations. With these modifications, the Wharton model shows a 2% change in the deflator and the DRI a 10% change.

Mork (1978b) provides the only detailed conceptual analysis of the inflationary impact of higher oil prices. He discusses the methodological problems in estimating the effect of changes in the cost of energy on the general price level. These methodological problems stem from two standard features of econometric models: the exclusion of the price of energy from any of the traditional price equations and the use of the GNP deflator as a measure of the overall price level.

According to Mork, the GNP deflator suffers from two shortcomings as a measure of the inflationary impact of energy price changes. First,

since it is a value added-deflator, it fails to properly reflect price changes in a primary resource like energy. Second, import price changes have no direct effect on the GNP deflator, a fact first noted by Pierce and Enzler (1974).

For these reasons, Mork constructs an alternate price index of the non-farm, non-primary energy sector of the private U.S. economy. This index is based upon a three-sector (primary energy, farming, and goods and services) model developed by Mork. Simulations with this model of the economy for the first three quarters of 1974 show that the energy price increase explains half of the "above-trend" annual inflation rate of 9.8%. Mork concludes (p. 25) that "since it took more than a doubling of energy prices to get an inflationary impact of the magnitude actually found, one can hardly expect energy prices to be a major inflationary force over reasonably long periods in the future."

INTERNATIONAL

The quadrupling of oil prices in one year left many economists, bankers, and statesmen sharing a common concern: "How do we pay for the oil?" The managing director of the IMF warned that the price increases in 1974 would probably produce "a staggering disequilibrium in the global balance of payments ... that will place strains on the monetary system far in excess of any that have been experienced since the war." And Treasury Secretary Schultz stated that many nations faced "literally unmanageable" problems. Pollack (1974, p. 452) lists some of the questions raised by the energy crisis. These include:

- Can the international monetary system sustain a transfer of wealth of such unprecedented dimensions without extensive disruption or even collapse ...?

- Will the consuming countries be able and willing to absorb the immense investments the oil-producing countries may wish to make?
- Will new financial mechanisms be necessary to assure reasonable stability?
- What will happen to currency values?

The answers to these questions and others like them are reviewed in the next section.

Balance of Payments

Discussions of the balance-of-payments implications of the energy crisis differ greatly depending upon when they were written. These analyses can be informally classified into three "eras"--pre-embargo, embargo, and post-embargo. Authors fortunate enough to have benefited from hindsight take a considerably more sanguine view of the problems created by the price increase than those caught in the hysteria immediately following the embargo.

The few papers published in the pre-embargo era illustrate the fragile nature of most of the assumptions underlying our energy forecasts. Only months before the embargo Frank and Well (1973) examined the background of the energy shortage and projected the balance-of-payments impact of oil imports in 1980. They base their projections on an assumed tax-paid cost of Arabian crude of $2.39/bbl in 1980. They also note that prospects for increased supplies from Latin America are bleak and fail to even list Mexico as a potential supplier.

The pre-adjustment commentaries can generally be characterized as doubting the resiliency of the financial system. Few of these commentaries ever reached the academic journals, appearing instead in the more

popular media. Pollack (1974) surmises that oil imports could easily approach $200 billion by 1985 with OPEC investable surpluses amounting to about $500 billion by 1980 and more than $600 billion by 1985. According to Pollack, "These magnitudes would seem to be enough to scuttle any monetary system."

Izzo and Spaventa (1973, p. 12) also state that "Authoritative bodies, like the IMF and the OECD, have attempted to calculate the immediate effect of this sudden and dramatic price rise on the current balances of importing countries. The results, as is well known, are staggering.... An unbearable strain is thus placed upon the payments situation of most industrialized countries and the import capacity of less developed, nonoil-producing countries."

Izzo and Spaventa (p. 12) make no attempt to "suggest solutions to a problem which, as things stand, has by some been defined [as] unmanageable." Instead, they explore some of the economic implications of the issues. They foresee three possible outcomes to the payments problem in the medium term, providing the terms of trade and oil consumption remain unaltered. The first outcome is a fall in the level of output of trade. The second is an evergrowing accumulation of claims on the resources of oil importers by oil exporters. And the third is a real transfer from the former to the latter.

Agmon and Laffer (1978) use the monetary approach to study the balance-of-payments impacts of the quadrupling of oil prices. They conclude that the rise in the price of oil will not lead to permanent surpluses or deficits in balance of payments. Instead, the higher oil price changes the distribution of income and hence alters money demands. The long-run impact

is a change in the distribution of world reserves. Of course, in the short run, countries can and do run substantial surpluses or deficits (since expenditures adjust with a lag to income). The adjustment comes about either through a reduction in the physical volume of imports of oil or through an increase in the physical volume of exports of other goods.

Rather than attempt to explain the magnitude and distribution of the balance-of-payments impacts of the embargo, most researchers focus on the adjustment process. The increased relative price of oil lowers the real income and wealth of consumers and importers of oil and raises the real income of producers or exporters of oil. Agmon and Laffer (1978), Crockett and Ripley (1975), Dornbusch (1975), Aschheim and Park (1975), Solomon (1975), Tumlir (1974), and Pierce and Enzler (1974) all clearly explain the need for some type of adjustment to these changed conditions. Dornbusch (1975, p. 210) states that "The required adjustment is one of a decline in expenditure and asset demands on the part of the losers and an increased level of spending and asset holding on the part of the gainers."

In contrast to the consensus about the need for adjustment to the higher oil prices, there appears to be considerable disagreement about the means to that end. Dornbusch argues that no institutional reform is necessary to accommodate the adjustment (a view very similar to the U.S. position at the Fund meetings). He supports this reasoning with two arguments (p. 215). First, "the market response to a changed world liquidity preference (increased desire for liquidity) is to make arrangements for intermediation." Second, "world liquidity preference is unlikely to have changed permanently."

In contrast to Dornbusch, other economists stress the need for the "recycling of oil money" to cope with serious payments imbalances. Recycling, according to Aschheim and Park (1975) can either be primary or secondary. Primary recycling schemes involve setting up intermediary institutions to directly channel oil-money from OPEC countries to needy countries. The Healey Plan, the OPEC Fund for Government Securities and the OPEC Mutual Investment Trust, George Ball's Fund for Capital Recycling, and Walter Solomon's plan all fall into the primary recycling category.

Secondary recycling schemes, on the other hand, are designed to redirect surplus oil money already invested in one group of oil-importing countries into the other group of poor or creditless oil-importing countries. The Kissinger-Simon plan and the plan initially proposed by the Secretary-General of the OECD both involve secondary recycling.

Crockett and Ripley (1975), Solomon (1975), and Izzo and Spaventa (1973) consider techniques for allocating this "recycled oil money." Crockett and Ripley derive optimal patterns of payment flows based on efficiency criteria and two simple macroeconomic models. They then use these patterns as a guide for distributing current account deficits among developed countries. After considering the movement of exchange rates, Crockett and Ripley suggest that current account deficits be shared as follows--two-thirds to three-fourths on the basis of optimum capital flows (tied to GNP and gross investment) and one-fourth to one-third based on expected shares in export growth to OPEC countries.

Izzo and Spaventa take a more parochial view and argue that countries least affected by the oil crisis and/or relatively well endowed with foreign assets should simply alleviate the situation of worse-off countries.

Other research into the effects of a rise in the price of world oil on the balance of payments includes the comments of de Carmoy (1975), Haberler (1976), Pollack (1976), Johnson (1976), Powelson (1977), Reed (1975), and Safer (1978).

Balance of Trade

Like so many of the balance-of-payments forecasts made during the embargo, the trade forecasts often erred by enormous amounts. Many people viewed the ballooning in the OPEC current account surpluses from $6 billion in 1973 to $67 billion in 1974 as the beginning of a sequence of large surpluses with no end in sight. MacLaury (1978) attributes these pessimistic beliefs to widely shared misperceptions about OPEC's speed in adjusting its imports to its export receipts, the reduction in demands, and the increased production of oil by other countries. MacLaury now sees an OPEC surplus of $20 billion or less in 1978 with future declines through 1980.

Solomon (1975) suggests a number of possible criteria for allocating these current deficits including the ability to reduce absorption of resources, economic size, rate of return on capital, potential for producing substitutes for OPEC oil, normal current surpluses adjusted for oil deficits and potential exports to OPEC. In comments on Solomon's paper, Whitman (1975, p. 81) notes that: "Another perennial issue that arises in this paper is whether governments can read the future better than the marketplace can. While Solomon apparently assumes that they can... history should make us cautious on this point."

With the present emphasis on energy, it is not surprising that several papers have appeared on the balance of trade in energy per se. For example,

Fieleke (1975) argues that a comprehensive measure of energy trade must explicitly incorporate both direct and indirect imports and exports of energy. Fieleke uses input-output analysis to estimate the quantities of energy resources embodied in U.S. imports and exports of goods and services. He concludes that U.S. imports are considerably more energy-intensive than U.S. exports. His figures also show that the U.S. terms of trade declined by more than 14% between 1973 and 1974.

Exchange Rates

When it comes to the analysis of exchange rates, scholars display a marked preference for letting the foreign exchange markets decide the impact of increased oil prices. Only Crockett and Ripley (1975) and Pollack (1974) attempt to forecast the future course of exchange rates. Crockett and Ripley predict two major moves in exchange rates with the second move reflecting the delayed increase in imports by OPEC countries. Crockett and Ripley expect the U.S. share in these increased exports to OPEC countries to equal its share in exports to these same countries during January-August 1974.

Pollack considers the outlook for individual currencies. He begins by reviewing the initial responses of exchange rates to the oil crisis. In the first few months following the embargo, the dollar performed very strongly and the yen and major European currencies declined substantially relative to the dollar. By February, however, these other currencies rallied and the dollar receded as the oil imports of other leading countries increased less than expected. Pollack concludes by saying (p. 465) that "the longer-term outcome will be dominated by capital flows and therefore defies prediction." However, Pollack suggests (p. 465) that "European

exchange rates should strengthen toward the end of the decade" and also warns against "under-estimating the long-term potential of the yen." In retrospect, Pollack did considerably better than the foreign exchange markets in forecasting future exchange rates.

Without attempting to forecast future exchange rates, Haberler (1976) and Pollack (1976) analyze the role of exchange rates in the adjustment process. Haberler argues that exchange rate changes and/or a floating of the rates are the appropriate responses to the oil price rise. Pollack disagrees. According to him, the conventional view does not look upon exchange-rate adjustments to oil deficits with equanimity. Because of OPEC's limited absorptive capacity, a parallel devaluation by all oil-importing countries vis-a-vis OPEC would do little good. Moreover, the deterioration in a country's current account results from deflationary forces. Attempts to correct this situation with exchange-rate adjustments would merely increase the current-account deficits of other oil-importing countries and worsen their unemployment problems. These countries would no doubt turn to import restrictions and export subsidies to protect their markets, thereby provoking a destructive spiral of restrictions and counter-restrictions.

Reserves, Tariffs, and Quotas

None of the studies surveyed specifically addresses the impact of changes in the world oil price on reserves, tariffs, and quotas, or vice versa. Agmon and Laffer (1978) do note that in a closed world system or a small country, the balance of payments equals the change in reserves. Mayer (1974), and Fieleke (1974) conclude that the oil price increases will

undoubtedly lead to an increase in global reserves. However, the distribution of this increase in reserves will be very uneven.

Several authors express concern over the possibility of increased protectionism. Freedman (1975) talks about nations engaging in competitive deflation while seeking to sell their goods in smaller and smaller export markets. Johnson points out that the crisis fortunately failed to cause a wholesale retreat from the liberal international trading system. Nordhaus (1974a) notes that the oil import quotas--part of the original "Project Independence"--were extremely disruptive. Nordhaus also analyzes the loss in welfare associated with the tariff on oil. Hay (1971) finds some reasons for questioning whether a tariff on oil is equivalent to a quota. Amacher, Tollison, and Willett (1973) review the effects of tariffs and quotas, an issue they say Hay omits from his analysis.

Pollack (1974) thinks that financial instability could turn out to be the biggest threat posed by the energy crisis, with recurring upheavals in the foreign exchange markets triggering protectionism.

Capital Markets

The quadrupling of oil prices impacted the capital markets in several ways. Dornbusch (1975) sees two major changes: (1) a shift toward public debt and away from private securities because of the increased private default risk; and (2) a shift in preferences towards more liquid liabilities. The second shift stems from the enormous increase in asset holdings by the OPEC nations, with their well known preferences for short-term, highly-liquid, assets.

According to Dornbusch, these shifts in portfolio preferences can be expected to result in declining and lower prices of private and long-term

securities, excess liquidity in some banks, and shortages elsewhere. As a result, short-term interest rates should decline and long-term interest rates should increase as the term structure of interest rates rotates counter-clockwise. Corden (1977) offers essentially the same conclusions.

The prospect of OPEC nations acquiring hundreds of millions of dollars of short-term securities raised doubts about the "absorptive capacities of the financial markets." MacLaury (1978), reminiscing about the embargo, recalls that many observers--including himself--"seriously questioned whether financial markets and institutions could cope with the unprecedentedly large financial transfers that the oil price increase set in motion." Mayer (1974) finds no major reasons why the Euro-currency markets should not make a large contribution to the intermediation of oil funds. However, he sees certain dangers because of the possibility of sudden shifts in the patterns of international capital flows. Pollack (1974) too feels that the Euro-currency market can recycle OPEC surpluses. Pollack also shares Mayer's concern about the danger of financial instability resulting from sudden and massive shifts of funds. Agmon, Lessard, and Paddock (1977) analyze the implications of this instability on the behavior of the oil-exporting countries. Finally, banker Paul Erdman (1976) turned these same worries into a best selling book, The Crash of 1979.

Widespread recognition of this potential for instability resulted in a number of proposals for reducing the volatility of Arab funds. Secretary of the Treasury Schultz recommended formation of a new multinational joint venture. Walter J. Levy suggested a buy-now, pay-later scheme. And a number of political economists argued that the IMF should issue new, value-guaranteed instruments to sop up the OPEC liquidity.

OPEC's desire for liquidity, while creating a potential for instability, at least alleviated the problems of foreign nationals acquiring controlling interests in U.S. corporations, an issue addressed by Reed (1975).

A change in the price of an imported commodity like oil also changes the demand for money, according to Pierce and Enzler (1974). A rise in import prices produces a corresponding rise in transactions, and hence, in money demand. But GNP, a commonly used proxy for transactions, fails to reflect this change (since the rise in the price of imports is offset by a corresponding rise in the cost of consumption and investment goods). For this reason, Pierce and Enzler recommend using GNP plus imports as the measure of transactions demand. An increase in oil prices increases the nominal value of transactions (GNP plus imports) and augments the demand for money at a given interest rate. If the money stock remains fixed, interest rates will therefore rise.

Consumption-Savings

According to Crockett and Ripley (1975, p. 287), "The inability of many oil exporting countries to spend their higher receipts in the short term or medium term may be thought of as an outward shift in the world savings schedule." Crockett and Ripley argue that this shift in the savings schedule can be expected to reduce interest rates and encourage capital accumulation at the expense of current consumption. (This argument ignores the change in risk preferences discussed in the previous section.) In addition, the deterioration in the terms of trade reduces real income and in turn reduces consumption.

Pollack (1974) shares a similar view of the impact of higher world oil prices on consumption. He sees the entire world experiencing a tendency for the share of consumption to drop and for that of savings to rise, with most of this increased savings occurring in the OPEC countries.

Capital Formation

Although many of the authors in this survey mention the connection between oil prices and investment, only Gunning, Osterrieth, and Waelbroeck (1976) investigate this issue in any detail. The SIMRICH model projects a much higher investment in primary energy production at a higher oil price, $218 billion more investment (over the period 1974-1985) if the oil price is $8.20 instead of $3.20. Another study by OECD projects a difference of $304 billion at an energy price difference of $6.87.

Tumlir (1974) provides further commentary on the impact of higher oil prices on investment. He sees the increased price of oil creating several incentives for investment. Energy-savings measures, the development of alternative sources of energy, and the elimination of capacity shortages all require additional investment. Tumlir also cites estimates from the Financial Times that investments in alternative energy sources could increase the rate of gross fixed non-residential investment by 50-100% in the next few years.

Not everyone thinks that the higher world oil prices will increase investment. Berndt and Jorgenson (1978) take a distinctly minority point of view, arguing that increases in energy prices provide an incentive to economize on both energy and capital by substituting labor and materials for fuel and equipment. As a result, Berndt and Jorgenson think the net

effect of higher oil prices will be a reduction in the rate of capital formation.

Regardless of the long-term effect of higher energy prices on investment, there can be little disagreement about the immediate impact. Because of the downturn in the economy following the embargo, real investment fell substantially. Serot (1978) and a number of other researchers use models of the economy to estimate the magnitude of this reduction.

CHAPTER V

ENERGY CAPITAL REQUIREMENTS

Hass, Mitchell, and Stone (1974) give two reasons for studying the capital needs and external financial requirements of the energy sector. First, capital costs dominate the price of energy, accounting for .89¢ of the 1.78¢ price per kilowatt hour in 1971. Second, the energy sector is much more capital intensive and much more dependent upon external capital markets than U.S. industry as a whole. According to Hass, et al. the petroleum and investor-owned electric utility industries only accounted for 4.3% of total corporate receipts in 1970. But their plant and equipment expenditures amounted to 20.9% of all such outlays and these industries raised 24.9% of all external capital. Other figures also support this point of view. According to the Federal Energy Administration's National Energy Outlook (1976), new plant and equipment expenditures by the energy extraction and processing industries ranged between 23% and 34% of total expenditures by all industries during 1965-1974.

Given the capital-intensive nature of the energy sector, it comes as no surprise that projections of the capital requirements of the U.S. energy sector abound. Among them are Pelley, Constable, and Krupp (1976), Hass, Mitchell, and Stone (1974), Carasso, et al. (1975), Gallagher and Zimmerman (1976, 1978), Gallagher, et al. (1978), Federal Energy Administration (1976), Ervik (1974), Energy Group, Bankers Trust (1976, 1978), Deonigi, et al. (1976), and Bullard and Pilati (1975).

Gallagher and Zimmerman (1976, 1978), Gallagher, et al. (1978), and Carasso, et al. (1975) base their projections on the Bechtel Energy Supply

Planning Model, a model designed explicitly for calculating the capital, labor, and material requirements of alternative energy facilities. This model is essentially a systematic planning method. According to Carasso, et al. (1975) it operates as follows:

- The user chooses a candidate future energy mix (coal, heavy fuel oil, high-BTU natural gas, etc.).
- A computer program calculates the number of new energy facilities by type needed to provide the specified energy mix.
- At user option the model locates the facilities in different regions of the U.S.
- The program next calculates annual requirements for capital, manpower, and materials for each energy and transportation facility from initial commitment to plant startup and for operation.
- Regional and national totals are then computed.

The Energy Supply Planning Model has been widely used to calculate the capital requirements for the energy sector. Table 5-1 gives projections for a number of different scenarios including the President's 1975 energy program, the Energy Modeling Forum coal reference case, and the 1977 National Energy Plan.

Despite its widespread use, the Energy Supply Planning Model suffers from several shortcomings. It essentially ties the calculation of requirements to fixed input-output coefficients. As a result, interfuel substitution, factor substitution, economies of scale, and technological changes are all ignored in the capacity expansion decision. In addition, the energy mix is determined independently of facility cost and these costs also appear to be independent of site location.

Deonigi, et al. (1976) use another input-output model, a modified version of Battelle's EXPLOR MULTITRADE-85, to analyze capital require-

TABLE 5-1

COMPARISON OF CUMULATIVE CAPITAL REQUIREMENTS
FROM THE BECHTEL ENERGY SUPPLY PLANNING MODEL

Scenario	Capital Costs 1977-2000 (Billions of 1977 Dollars)
1977 National Energy Plan	1,520
Maximum Fossil	1,490
Maximum Electrification	1,695
Maximum Decentralization	1,885
Department of Energy	1,458
Energy Modeling Forum	1,608
Department of Commerce	1,459
CONAES	1,365

ments and capital formation for alternative energy supply patterns. Judging from their description of EXPLOR, this model appears to be ill-suited for its task. For example, Deonigi, et al. (p. 30) describe their derivation of investment forecasts as follows:

> Forecasts for capital requirements or investment by sector are prepared exogenously to the EXPLOR model. These forecasts are based on recent trends, which are represented as a ratio of productive investment to output for each sector. (The investment values refer to annual investments by sector as opposed to capital stock.) This ratio may then be subjectively modified to reflect additional information such as anticipated changes in technology, increased investment for environmental pollution control, and price increases for selected commodities. The modified ratio is then used as a basis for forecasting investment requirements.
>
> In EXPLOR, the importance of time lags in the investment program and other time-dependent factors is minimized or averaged because a 10-yr. increment of time was selected.

Deonigi, et al. study three scenarios: (1) Business as usual, (2) new energy supply systems providing 7% of domestic requirements by 1990 and 10% by 2000, (3) new technologies providing 5% of domestic requirements by 1980, 10% by 1990, and 15% by 2000. It turns out that capital requirements under these three scenarios are virtually identical. The energy sector capital requirements from the business as usual scenario for 1980, 1990, and 2000, together with cumulative requirements, all expressed in billions of 1970 dollars, are as follows:

Year	Total Energy Investment	Percent of Total Investment
1980	44.7	25
1990	65.7	25
2000	106.4	27.8
1971-2000	1,727.5	26.0

Tessmer (1976) gives a detailed discussion of the difficulties in deriving input-output capital coefficients like those used in the Bechtel and Battelle models. He makes a number of recommendations for future research on this topic including the following: (1) Coefficients should be estimated within a framework of coefficients for the whole economy; (2) coefficients should accurately reflect the composition of current inputs used by the construction sectors to produce buildings and structures; (3) capital payments should be deflated; (4) the level of detail in the process coefficients should be compatible with the sectoral coefficients; and (5) capital coefficients for technological processes should be meshed with those for the input-output sector containing those processes.

Unlike Bechtel and Battelle, Bankers Trust primarily relies on expert judgment drawn from a variety of sources in preparing its forecast of capital needs by the energy sector. The Bank's estimates appear in a variety of publications including Pelley, Constable, and Krupp (1976), Energy Group, Bankers Trust (1976, 1978), Hass, Mitchell, and Stone (1974), and the Federal Energy Administration (1976).

In analyzing the energy sector's capital needs, Bankers Trust first forecasts the country's economic environment. It then estimates the types and amounts of energy needed in BTUs for each consuming sector of the economy (household and commercial, industrial, transportation, and electricity generation). Next these demands are disaggregated by fuel type (petroleum, coal, natural gas, etc.). The supply from alternative sources is then calculated and capital expenditures for each source derived by multiplying estimates of capital costs per unit of capacity by projected increases in supply. In some cases working capital requirements are added

to these figures. By definition the difference in the aggregate demand and supply for energy equals the amount of petroleum imports.

The 1976 Bankers Trust report also includes a comparison of capital requirements under three different energy scenarios. The second scenario differs from the reference case with respect to imports of oil and gas, i.e., it assumes energy independence by 1990. This energy independence is achieved by using syngas and synoil. The third scenario involves independence by 1985, again achieved by the use of syngas and syncoal. Scenario II increases capital requirements for the period 1976 to 1990 by $103.5 billion; Scenario III, by $123.8 billion. These increases amount to 13.7% and to 16.4% of capital requirements in Scenario I. However, these percentages understate the true impact on the capital market since the incremental expenditures bulge very large in several years. For example, Scenario III implies a jump in capital requirements of $22.9 billion in 1984, a gain of 43.5% over Scenario I.

The Bankers Trust projections of capital requirements illustrate the difficulties in comparing different projections, even when they come from the same source! For example, the 1976 report does not state whether the estimates of capital requirements are in constant or current dollars. Nor does this report say whether or not working capital is included in the estimated capital requirements. And neither the 1976 nor the 1978 reports carry the dates of the forecasts. Moreover, the different energy sources are defined differently in each report. Finally, no attempt is made to reconcile the truly enormous differences in the two sets of projections. Table 5-2 shows the historical capital requirements for 1976 from the 1978 report and the projections for this same year in the 1976 report.

TABLE 5-2

COMPARISON OF BANKERS TRUST REPORTS OF
ENERGY SECTOR CAPITAL REQUIREMENTS IN 1976

1976 Bankers Trust Report		1978 Bankers Trust Report	
ENERGY SOURCE		ENERGY SOURCE	
Oil and Gas		Oil and Gas	
Exploration & Development	$ 9,221	Exploration & Development	$17,467
Refining	1,750	Refining	1,918
Tankers	368	Marketing	596
Pipelines	1,820	Transportation	3,274
Deepwater Ports	300	Working Capital	4,275
Marketing	600		
		Coal	
Coal		Production	1,641
Production	832	Transportation	844
Transportation	823	Working Capital	124
		Electric Utility	
Synthetic Fuels		Generation	16,184
Syngas from Petroleum	34	Flue Gas Desulfurization	--
Syngas from Coal	30	Transmission	2,641
Syncrude from Shale	15	Distribution	4,090
Syncrude from Coal	--	Miscellaneous	1,146
		Working Capital	2,862
Electric Utilities			
Generation	8,895	Gas Utility	
Transmission	1,840	Transportation	531
Distribution	4,893	Distribution	926
Nuclear Fuel Cycle	505	Miscellaneous	609
Flue Gas Desulfurization	432	Working Capital	2,200
Miscellaneous	781		
		Other	
		Nuclear Fuel Cycle	473
		Solar	80
		Synfuels	20
TOTAL ENERGY INDUSTRIES (Current Dollars)	$33,139		$61,901

Ervik (1974), Hass, Mitchell, and Stone (1974), and the New York Stock Exchange (1974) also project capital requirements of the energy sector. Ervik reports some preliminary results from a systems dynamics model of energy resource depletion. According to Ervik, the depletion of energy resources increases the capital-output ratio for the energy sector and creates a greater need for investment. This problem is exacerbated by the increasingly long lead time required for nuclear and synthetic energy facilities. Ervik argues that the fraction of GNP devoted to investment in the energy sector climbs to around 50% in the 1980s and 1990s -- a percentage stretching the limits of credibility.

Although dated, the study by Hass, Mitchell, and Stone (1974) provides some insightful comments on energy sector capital requirements. Hass, et al. (p. 9) define the energy sector as consisting of "all firms or governmental agencies associated with the extraction, processing, and delivery of energy or energy materials to the ultimate consumer." Their projections of capital investment in the energy industry are presented in Table 5-3. Energy sector capital investment is expected to grow from $24.5 billion in 1971, to $36.1 billion in 1975, $50.7 billion in 1980, and $66.5 billion in 1985. Hass, et al. also express these capital expenditures as a percent of total projected business capital expenditures. They use two projections of total expenditures, one by Bankers Trust which they feel seriously overstates these outlays and another more conservative estimate reflecting a real growth rate of 4% in total outlays. Energy sector capital expenditures as a percent of these more conservative projections of total business capital expenditures increase from 20.8% in 1971, to 27.7% in 1975, to 32.0% in 1980, and to 34.5% in 1985.

TABLE 5-3

ENERGY SECTOR CAPITAL INVESTMENT, 1971-1985

Sector	Actual Current Dollars 1971	Projected 1970 Constant Dollars 1975	1980	1985
Petroleum (including synthetics)	$ 6.8	$12.0	$17.0	$22.0
Electric Utilities (private and public)	14.6	18.6	26.8	37.6
Natural Gas Transmission and Distribution	2.1	4.0	4.0	4.0
Coal Production and Transportation	n.a. 1.0*	1.5	1.5	1.5
Nuclear Fuel Cycle	n.a.	0.0	1.4	1.4
Total Energy Industry	$24.5	$36.1	$50.7	$66.5

*Guestimate for comparative purposes.

Source: Hass, Mitchell, and Stone (1974, p. 104).

The New York Stock Exchange (1974), apparently relying primarily upon other forecasts, projects plant and equipment spending of $824 billion (current dollars) during 1974-1985. This equates to a 12.7% annual rate of growth during the period from 1973-1985.

The U.S. Bureau of Economic Analysis (1975) and Vaccara (1977) also report estimates of capital investment related to energy. The BEA-Vaccara study relies heavily upon Federal Energy Administration figures but makes no attempt to explicitly integrate those numbers into its estimates. Instead, BEA (p. 6) analyzes "the changing geographical and/or technical aspects of producing, transporting, and utilizing energy products, as they were projected to 1980 and beyond...." It then evaluates "the impact of these changes on the direction and magnitude of the observed trends in the historical capital/output ratios of the major energy producing and consuming industries." BEA projects substantial increases in capital investment in the petroleum, mining, electric utility, and other energy-related industries.

O'Toole (1976, p. 51) reviews several different estimates of capital requirements and concludes that "the size and scope of the new or continued investment in energy over the next ten years [1975 to 1985] will be staggering." These estimates range from $550 billion to $1.7 trillion. O'Toole also reports the results of a Delphi study. According to the Delphi panel of experts, the annual requirements of the energy sector will be about $60 billion in 1985, not the $70 to $100 billion forecast in other studies. This considerable difference in estimated requirements can probably be attributed to the panel's belief in greater future use of less-capital intensive technologies, especially advanced batteries and methanol.

Several studies provide separate estimates of the capital needed to implement energy conservation. As the Federal Energy Administration (1976) points out, these conservation related expenditures are difficult to project because of the problem of telling which part of the cost of new equipment is an investment in conservation. FEA presents three different estimates, based on alternative assumptions about capital requirements. Cumulative capital requirements for energy conservation during 1975-1984 amount to $164, $242, or $327 billion out of a total expected investment of $4,710 billion.

So far all the projections of energy sector capital requirements have focused on the direct capital needed to build energy supply and transportation facilities. Bullard and Pilati (1975) argue that the indirect capital requirements of the energy sector are too large to be ignored. According to Bullard and Pilati, industries supplying materials to the energy sector need about 80 cents of capital equipment to produce each dollar of materials. This implies additional billions of dollars in energy-related capital requirements.

ENERGY-ECONOMY INTERACTIONS

To date most of the interest in energy sector requirements stems from considerable concern about possible capital shortages. The Energy Group, Bankers Trust (1978, p. 2) summarizes the reasons for these fears about capital shortages as follows: "In short, the fear of a capital shortage stems from the widely held belief that the capital requirements of the energy industries will be enormous and will outrun the ability of the capital markets to meet them." These capital shortages would presum-

ably hamstring the development of additional energy supplies, lead to sharp increases in energy prices, and cripple the economy. The Energy Group, Bankers Trust (1978, p. 2) provides a colorful description of these economic consequences:

> It is unnecessary to detail the economic consequences which would result from a severe capital shortage. Our economy has survived several moderate credit crises in the last decade, and everyone has had a small but recent taste of the results. A severe credit crunch would be but a small part of the fallout from an energy induced capital shortage of any dimension. In brief, a shortage could lead to a sharp rise in interest rate levels, a slowdown of economic growth, growing unemployment, instability in the price indices, business failures, disintermediation, and a generally lower average standard of living.

The fears generated by visions of an energy-related "capital gap" no doubt prompted President Ford's proposal for an Energy Independence Authority with $100 billion to finance energy projects (see "Federal Energy Money: Can the Government Fill the Capital Gap?" and Weidenbaum and Harnish (1976)). Perhaps the most frequently cited evidence in support of the expected capital shortage comes from the New York Stock Exchange (1974). The usually staid NYSE introduces its report (p. i) on the capital needs and savings potential of the U.S. economy by saying that "the twin ogres of escalating inflation and soaring interest rates have tightened their grip on the U.S. economy...." The findings of the NYSE study do justice to this melodramatic beginning. The NYSE projects a "capital gap" of $650 billion between 1974-1985.

The NYSE points out that this capital shortage is, by definition, an ex ante concept. Such a shortage never actually appears. Instead, it is evidenced by higher interest rates and reduced credit availability. Unfortunately, the NYSE never attempts to qualify the impact on the economy, settling instead for loose generalities like "Millions of Americans

who dream of a home in the suburbs will have to forego their hopes and aspirations" (p. 26).

Friedman (1975) also examines the capital shortage question and concludes that financial considerations may act as effective constraints on the amount of fixed investment undertaken by the U.S. economy during 1977-1981.

Fears of capital shortages appear to be misplaced. Hass, Mitchell, and Stone (1974, p. 25) provide the economist's traditional rebuttal to the very idea of a shortage by stating that "In a free market there can be no such thing as a shortage." The reason for this impossibility is that "Any potential deficit in supply is always removed by some increase in price, and any potential surplus is removed by a fall in the price, there always being some price which the market will clear." However, Hass, et al. also point out that shortages can and do exist in the presence of price controls. Cox and Wright (see U.S. Congress (1973)) offer a detailed description of these controls.

Not surprisingly most of the studies by economists of the capital requirements of the energy sector find no capital shortages or other severe difficulties standing in the way of the energy sector. Three of these studies explicitly relate capital requirements to capital availability. Hass, et al. compare their capital expenditure projections with the estimates of available capital and conclude that there will be no "capital crunch" or financial problems. Energy Group, Bankers Trust (1978) predicts no rise in the energy industry's share of the credit and capital markets beyond 1977 and no shortage of capital during 1978-1982. Energy Group, Bankers Trust (1976) finds that the capital markets can handle the requirements of the energy industries without undue strain, even in the

case of energy independence by 1985.

The Federal Energy Administration (1976) concludes that a general shortage of capital can be avoided. Bosworth, et al. (1975) believe that capital needs, though large, are manageable in the expanding economy. Although Deonigi, et al. foresee a small capital gap, they do not think it will create serious problems.

Sinai and Brinner (1975) and Sinai (1976) use the DRI model to answer questions about a possible capital shortage. Two model simulations are discussed, both extending through 1990. The Control Long 5/75 solution provides the basic framework for most of their analysis. It corresponds to a gradual approach to full employment in 1981 under the assumption of moderate stabilization policies. The Control Long scenario posits strong growth from the second half of 1975 to early 1977, a slowdown in the second half of 1977 and recovery to full employment by 1981.

Sinai and Brinner foresee no severe capital shortage before 1980, either in terms of flows of funds or a shortage of physical capacity. Although the cost of financing capital expenditures increases during 1981 to 1985, Sinai and Brinner conclude (p. 6) that "capital expenditures can be financed without the disruptive strains that characterized the U.S. economy from 1965 to 1974." They see no problems with Federal budget deficits "crowding out" private borrowers. Nor do they project any serious credit crunches.

Wachtel, Sametz, and Shuford (1976) provide a very detailed review of forecasts of capital availability. They cite twelve different forecasts (from ten different sources) of investment and savings as a percentage of GNP. Only three of these forecasts (one by the NYSE) suggest a capital shortage in the near future. Wachtel, Sametz, and Shuford con-

clude that real resource availability will not be a problem but that stability in the financial markets will require major structural developments by financial institutions. They believe that gross private domestic investment will be only a slightly larger fraction of GNP than in the past (partially because of a reallocation of capital away from residential investment towards business fixed investment).

In addition to these empirical investigations of capital shortages, several studies attempt to provide a theoretical framework for analyzing the question of capital shortages. In particular, Eisner (1977) examines the myths and realities about capital shortages and Feldstein (1977) attempts to answer the question: Does the United States save too little? According to Eisner, a capital shortage implies either a failure of markets to clear (because of fixed or sticky prices), or some externality. Eisner goes on to criticize the Vaccara-BEA study. Despite the fact that this study provides "the most meticulous, thorough and detailed estimate of business fixed investment 'requirements'," Eisner finds a number of deficiencies, including an extraneous estimate of full employment and the sectoral composition of GNP, fixed capital-output ratios which do not respond to changing prices or interest rates, and arbitrary assumptions about discards and/or retirements. These assumptions put the capital processes in a strait jacket. Indeed, Eisner feels that the very phrase "capital requirements" creates a misleading impression of needs which must be met, regardless of economic circumstances.

Eisner notes that the decisive constraint on capital formation may be in the supply of saving. Feldstein explores some of the reasons why the U.S. saves a lower percentage of its income than almost every other industrial country. Feldstein concludes that the U.S. saves "too little"

because of taxes and social security. A recent survey article by Furstenberg and Malkiel (1977) on government and capital formation covers these and related topics in detail.

Missing Interactions

The thoughtful bystander can only view the literature on capital requirements with dismay. The debate about capital shortages appears to have diverted everyone's attention from truly important issues in this area. In particular, how does capacity expansion in the energy sector impact the prices of capital and other factors of production, interest rates, productivity, etc.? This oversight appears especially serious given the disproportionately large percentage of total business capital outlays going to the energy sector.

CHAPTER VI

THE ENERGY/GNP RATIO

Much of the debate about the relationship between energy and the economy has focused on a single numerical measure -- the energy/GNP ratio. This chapter provides a brief summary of research into energy/GNP ratios and discusses the place of this ratio in the study of energy-economy interactions.

INTERNATIONAL COMPARISONS OF ENERGY CONSUMPTION

The energy/GNP ratio, usually with GDP (Gross Domestic Product) in the place of GNP, sees frequent use in international comparisons of energy consumption. Often these comparisons stress conservation possibilities. The typical argument proceeds as follows: Other industrialized countries with similar standards of living (Japan, West Germany, and especially Sweden) consume much less energy per dollar of gross domestic product. Therefore, the U.S. can substantially reduce its consumption of energy without any adverse consequences to the economy.

Arguments that conservation measures, price-induced or otherwise, can easily cut energy consumption by 30 to 40% imply a very loose connection between energy and the economy. Partly in response to this widespread and questionable use of comparative energy/GDP ratios and policy declarations, Resources for the Future and the Electric Power Research Institute sponsored a workshop on international comparisons of energy consumption. The proceedings of the workshop represent one of the single best references on comparative studies of energy/GDP ratios. The editor

of these proceedings, Joy Dunkerley (1978), provides an excellent summary of the literature. According to her, the largest number of comparative studies consists of sectoral analyses. These sectoral analyses typically take the energy/GDP ratios of several countries and disaggregate them as far as possible. At the very least, this disaggregation process usually involves breaking consumption down by major demand categories such as transportation, industrial, residential/commercial, etc.

Most of these comparative studies attempt to distinguish between structural differences and intensity differences. According to Dunkerley (p. xiv), structure covers a variety of factors including the following:

- Size of industrial sector
- Importance of energy-intensive industries
- Differences in product mix
- Vintage of energy-using capital stocks
- Climate and population density
- Propensity to travel
- Factors effecting use of energy and other input factors
- Lifestyle attributes

On the other hand, the term "energy intensity" refers to the amount of energy used to produce reasonably homogeneous goods or to conduct similar activities. Energy intensity, not structure, is the variable of interest in these comparative studies. It presumably shows how much less energy can be used in the economy, i.e., it measures the potential effectiveness of conservation.

Input-output analyses provide one way of separating structural factors from energy intensity. Several of the RFF studies, Bullard and

Hannon (1976), Bullard and Foster (1976), and Reardon (1976) use input-output analyses for this purpose. Bullard and Hannon and Bullard and Foster relate energy demand to four key variables: U.S. population, per capita GNP, a vector of goods and services making up GNP (structure), and a vector measuring the energy required to produce a dollar's worth of each good and service (intensity). They note that in order to decouple per capita energy consumption from per capita GNP, either structure or energy intensity must change. Bullard and Hannon find little change in either of these factors during 1963 to 1967. Instead, increases in GNP and population caused substantial increases in energy consumption.

Dunkerley summarizes the results of the RFF studies. Apparently there is general agreement about the considerable flexibility in energy use. In other words, conservation appears to hold much promise. There is also virtual unanimity about the misleading nature of international comparisons of aggregate energy/GDP ratios.

Darmstadter, Dunkerley, and Alterman (1977) provide one of the most detailed comparisons of energy/GDP ratios. They look at nine industrialized countries: U.S., Canada, France, West Germany, Italy, Netherlands, United Kingdom, Sweden, and Japan. Darmstadter, Dunkerley, and Alterman conclude that four identifiable categories account for over 60% of energy/GDP variability -- passenger transport, industry, residential space conditioning, and freight transport. Furthermore, structural factors explain about 40% of the overall difference and intensity factors the other 60%. Darmstadter, Dunkerley, and Alterman (1978a, 1978b) reiterate these findings. Darmstadter (1971) provides an immense amount of data on energy consumption and economic activity in the world. Linden, Parent, and

Seay (1979) also provide information on energy/GDP ratios across countries.

ECONOMIC GROWTH AND GROWTH IN ENERGY CONSUMPTION

As Berndt and Wood (1974) point out, the energy/GNP ratio has been extensively used to summarize the relationship between economic growth and growth in energy consumption. For example, Schurr (1977) studies the historical record of the energy/GNP ratio between 1880 and 1975. He notes significantly different patterns in the trend of this ratio. It increased persistently until the 1910s, fell during the years between the two world wars, and remained comparatively level after World War II. Schurr argues that this ratio showed no signs of price responsiveness during this entire period.

Perhaps because of this seeming constancy, numerous forecasters base their estimates of future energy consumption on assumed energy/GNP ratios and projections of GNP. These forecasts often extend very far into the future. For example, Lichtblau and Frank (1978) attempt to forecast energy demand in the non-Communist world to the year 2005. Before making these forecasts, they review a number of energy-economic growth coefficients from different sources. Most oil company forecasters appear to have reduced their energy/GNP growth coefficients to a range of 0.8 to 0.9 from the "widely used historical ratio of 1.0." These downward revisions are intended to indirectly incorporate the negative impact of higher energy prices on energy consumption. Some assumed ratios for the period 1975 to 1990, together with their sources, are as follows:

Morgan Stanley	.80
Texaco	.86
Sherman Clark Associates	.60
Royal Dutch/Shell	.82

Lichtblau and Frank opt for energy/GNP growth coefficients ranging from .7 to .8 for the period 1980 to 1985.

In addition to its forecasting uses, the energy/GNP ratio also serves as a frequent reference point in general discussions of the relationship between energy and the economy. It appears in one form or the other in books by Richardson (1975), Sonenblum (1978), and Banks (1977). Meinel and Meinel (1978) study energy/GNP trajectories (time-series data) for the U.S. (1893 to 1975) and for seven industrialized nations, including the U.S. (1960 to 1974). They conclude that, contrary to popular belief, it takes almost as much energy to generate a dollar increment of new GNP in Sweden as it does in the U.S. Moreover, no country has been able to produce an increase in income without an increase in energy consumption. Silver (1975) also looks at a variety of energy/GNP ratios.

The close tie between energy consumption and GNP raises the inevitable question of causality. Does GNP determine energy consumption, or does energy consumption drive GNP, or do energy and GNP both influence each other? Kraft and Kraft (1978) attempt to determine the direction of this causality by using a simple statistical test. They conclude that the level of gross energy consumption has no causal influence on economic activity. Kraft and Kraft are not alone in this belief. Anderson (1975), Williams, Boyd, and Crow (1978), National Research Council (1978), Allen et al. (1976), Bernstein, et al. (1975), and numerous studies mentioned

by Verleger (1974) assume no energy-economy interactions (some, but not all of these studies, simply relate energy growth to the projection of economic growth).

SHORTCOMINGS IN THE ENERGY/GNP RATIO

As a simple aggregate measure of the relation between economic growth and energy consumption, the energy/GNP ratio is without parallel. However, it is not without substantial shortcomings, as numerous researchers have pointed out. Turvey and Norvay (1965) note the difficulties inherent in measuring energy consumption with a physical measure like the BTU. Parent and Linden (1977) feel that it is difficult if not impossible, to put energy/GNP ratios for different countries on a comparative basis. Differences in purchasing power parities and inflation rates and changes in exchange rates further complicate these comparisons.

Berndt and Wood (1974) provide the most telling argument against the use of an energy/GNP ratio. They show that the energy/GNP ratio only has a consistent economic interpretation under highly restrictive conditions. They base their analysis upon an aggregate production function with four factor inputs: capital, labor, energy, and intermediate materials. Assuming a homothetic cost function, Berndt and Wood show that the energy/GNP ratio depends upon the structure of technology summarized in the cost function, and/or changes in the relative prices of the factor inputs. Only if relative prices remain constant or "if prices don't matter" (the Allen partial elasticities of substitution are zero) do changes in the energy/GNP ratio correspond solely to non-neutral changes in the structure of technology. Berndt and Wood's economic interpretation of the energy/

GNP ratio appears to invalidate much of the work on energy/GNP ratios. This work ignores or only indirectly considers changes in prices. Moreover, it raises doubts about even attempting to capture the relationship between energy and the economy with the energy/GNP ratio.

CHAPTER VII

STOCKPILING, ENERGY R&D, AND CONSERVATION REGULATIONS

STOCKPILING

Stockpiling makes it possible to adjust the time path of imports, thereby altering both the timing and the magnitude of losses of real income and reductions in the trade balance. Although there are costs to stockpiling oil, these inventory costs may be offset by benefits related to less frequent and less severe energy shortages.

Even though frequent mention is made of stockpiling, especially in connection with the Strategic Petroleum Reserve (SPR), few studies explicitly analyze the cost and benefits of storing oil. Of these studies, Newlon and Breckner (1975) provide one of the most detailed investigations of stockpiling. They begin by reviewing the U.S. need for secure oil supplies -- a need growing ever greater because of increasing imports from the Middle East and North Africa and a declining or at best stable domestic capacity. Congressional reaction to this need eventually resulted in a bill providing for a Strategic Petroleum Reserve. But Newlon and Breckner argue for an alternative approach to achieving oil security. They term this approach the Oil Security System (OSS); it consists of a system of incentives for private firms to build up emergency supplies of oil. In particular, "imports backed by adequate privately owned emergency oil supplies are always permitted to enter the United States free of any other restriction" (p. 7).

Under the Newlon and Breckner system, importers must own or buy

commitments for enough oil to replace their imports during a specified period of time. This "emergency supply" consists of working inventories of oil, spare capacity, or speculative stores of oil. In a competitive market for import allowances, the price of an allowance equals the cost of buying enough commitments to obtain the allowances directly from the government. Newlon and Breckner calculate the benefits from an OSS under different assumptions about elasticities of demand and supply for oil, oil storage costs, etc. They conclude that an OSS would have been significantly better for consumers than the import quota actually used in the 1960s. Emergency backing for imports would have increased from seven months to two years and one month. Or prices could have been reduced by 10%, while maintaining backing for one and a half years of imports.

Newlon and Breckner never provide an explicit measure of the impact of their system on the economy. Tietenberg (1976) actually estimates the losses imposed by potential embargoes under several different scenarios and compares these losses with the cost of alternative oil storage programs. Tietenberg bases his estimates upon a microeconomic framework explained by Areskoug (1971) and projections of key energy variables from the FEA energy modeling system. As Tietenberg points out, the economic losses incurred during an embargo depend upon the size of the embargo, its duration, and the year the embargo occurs. With an assumed price of $7.00 a barrel of crude oil, a six month embargo costs $38.3 billion in 1977, $49.5 billion in 1980, and $154.7 billion in 1985. At an $11.00 price, the costs only amount to $14 billion in 1980 and there are no costs in 1985. These low cost figures reflect the FEA assumption of a very substantial reduction in the demand for energy at higher prices.

Tietenberg also presents estimates of the cost of stockpiling oil. Capital costs amount to $1.23/bbl., maintenance costs equal $.0141/bbl., and the cost of purchasing oil is either $7 or $11 a barrel. Comparing these costs to those of embargoes, Tietenberg concludes that the benefits of stockpiling considerably outweigh the costs. Given a 50-50 chance of continued high prices (an assumption unfavorable to stockpiling) and two embargoes during the next eleven years, the present value of expected costs equals $51.8 billion without stockpiling as compared to $26.0 billion with stockpiling.

Other authors, using different techniques, also find stockpiling to be a desirable policy. Nordhaus (1974a) concludes that oil storage programs considerably reduce the total losses associated with embargoes. Randall (1977) uses cost estimates from MIT (1974) to argue (p. 43) that "considerable insurance against an embargo can be purchased at a relatively low price." Kymn and Page (1978) use an eighty-six-order interindustry transactions table to assess the forward and backward linkage effects of energy sectors on the U.S. economy. They find very strong forward linkages for crude petroleum, implying that either the public or the private sector or both should stockpile oil.

None of the studies of stockpiling cited so far explicitly incorporate uncertainty into the analysis. And yet, the principal rationale for stockpiling is the uncertainty about supply from foreign countries. Tolley and Wilman (1977) attempt to build this uncertainty into their model of stockpiling. This model has already been partially described in an earlier section on embargoes. Their approach to stockpiling resembles the formulation of the original inventory model by Arrow, Harris,

and Marschak (1971). The only differences are that their loss function is derived from market demand with the addition of external costs (such as the increased unemployment caused by an embargo) and there are no in-and-out costs. Tolley and Wilman conclude that, in the absence of embargo externalities, market behavior brings about optimal stocks. However, with externalities, the government may be forced to assume complete responsibility for embargo stocks. Tolley and Wilman provide no estimates of the impact of stockpiling on the economy.

Nichols and Zeckhäuser (1977) also develop a theoretical model of stockpiling strategies (again with no empirical estimates). They base their analysis upon a multiperiod framework and game theory concepts. Nichols and Zeckhauser initially use a two-period model with zero production and storage costs and a single buyer and a single seller. They reach the surprising conclusion that both the producer and the seller benefit from stockpiling. Moreover, the stockpiling agency buys high and sells low. They then extend their model to ten periods, and two or more consuming nations interacting in various ways (partial alliance, follower-follower, leader-follower, etc.). Regardless of the assumptions made, the oil producing cartel always benefits from stockpiling.

ENERGY R & D

The energy crisis prompted substantial increases in expenditures for energy research and development (R&D). Tilton (1974) believes that government spending doubled between 1973 and 1975, going from $627 million to $1,389 million. Private expenditures also rose significantly, increasing by about 20% from $1,000 million to $1,200 million.

Energy R&D resembles energy capital investment in that it involves an immediate outlay of funds in exchange for a stream of returns in the future. But there are also several differences between R&D and investment. As Searl and Perry (1974) note, the payoff from R&D usually comes only after very long lead times and involves great uncertainty. R&D also appears to be less capital intensive and uses a different mix of labor skills than direct energy investment. Finally, R&D usually impacts the cost of production rather than simply increasing output.

Despite the avowed importance of energy R&D, only a scanty literature exists on this topic. Indeed, Gilbert and Stiglitz (1978b, p. 3.4-1) argue that energy R&D has "escaped attention" although "in policy terms it may even be the most important single issue" in the area of exhaustible resources. They go on to say that "An obvious reaction to the brute fact of resource limitation is to attempt to avoid the consequences of this limitation by inventing a substitute -- that is, by allocating resources to research and development (R&D)."

Gilbert and Stiglitz attempt to remedy this situation by looking at R&D in an economy-wide or macroeconomic context. They develop a simple model in which output depends upon only two inputs, capital and resources. This output can be used for consumption, or investment, or R&D. Investment and R&D both feedback to the economy by increasing the inputs available for production. Gilbert and Stiglitz use the model to simulate the outcomes with a variety of discount rates and efficiency parameters (relating the change in the stock of knowledge to R&D activities). These simulation results show the time paths of the capital stock, output, consumption, and expenditures on R&D. Unfortunately, these results reflect

several very unrealistic assumptions made by Gilbert and Stiglitz. For example, they assume that any new technology discovered with R&D expenditures makes no use of existing stocks of capital and resources. Moreover, they ignore labor.

Manne and Richels' (forthcoming in Energy) decision analysis of the U.S. breeder reactor program probably represents the single best effort at quantifying the interaction between energy R&D and the economy. Manne and Richels use Manne's ETA-MACRO model to assess the economic benefits of a breeder R&D program. According to Manne and Richels (p. 20), "these benefits equal the difference in the present discounted value of the U.S. economy's future economic consumption (1975-2050), with or without the plutonium reprocessing technologies...." Since the breeder reactor does not become economically competitive with the light water reactor until after the year 2000, a no-breeder policy does not make itself felt until after the turn of the century. However, by the year 2020, breeder benefits amount to $51 billion or 1.3% of aggregate consumption. In the reference case, the breeder program adds about $198 billion to the present value of aggregate consumption between 1975-2050 (assuming a 5% after-tax rate of discount). Manne and Richels note that this is a relatively small macroeconomic effect, less than .4% of the present value of aggregate consumption of $48,407 billion. Even in the case of high energy demand and a high cost to non-electric alternative energy systems (AES) the breeder benefits "only" amount to $291 billion. These benefits must be balanced against some $5-7 billion of discounted R&D cost -- a tremendously high return on the R&D dollar. This, of course, assumes that the reference case holds true. In the event of low energy demand or low AES costs, benefits are negative.

For that reason, Manne and Richels incorporate probabilities into their analysis and also calculate expected net benefits.

Adar and Manne (1977) and Nordhaus (1977c) also investigate the economic benefits from R&D on nuclear reactors. Adar and Manne (1977) use the Manne ETA model to compute benefits. Nordhaus employs the Nordhaus Bulldog model. Unlike ETA-MACRO, the Bulldog model makes no allowance for energy-economy interactions. Nordhaus concludes that the expected discounted (at 6%) net benefit of developing either an advanced converter or breeder by the year 2020 only amounts to $3 billion. Nordhaus also measures the value of early information and calculates the economic insurance premium for advanced reactors.

Several authors study the impact of new energy technology in the context of input-output analysis. I-O analysis not only makes it possible to focus on the interactions between different sectors of the economy, but also provides for the linking of microeconomic engineering studies to macroeconomic models. Just (1974) and Just, Borko, Ashmore, and Parker (1975) examine the economic impact of new energy technologies (such as high-BTU and low-BTU coal gasification and the gas turbine topping cycle) and the effect of new technologies on the relationship between growth and energy use and total investment in the U.S.

Just derives the technological and capital coefficients in his input-output model from extensively modified engineering design studies. The new coefficients are incorporated into the I-O framework by using a simple weighting scheme. The weights depend upon the fraction of the total production and capacity of each sector taken over by the new technology. In order to measure the impact of the new technology, the weighted coefficient

column vectors are substituted into the coefficient matrices. Just finds that the new energy technologies impact selected capital goods industries but leave GNP, total investment, and private expenditures virtually unchanged. This absence of macroeconomic impacts can either be attributed to the small scale of the new technologies or to the absence of a macroeconomic structure in the Just model. Without a macroeconomic structure, it appears to be physically impossible to capture the effects of new technologies on economic growth/productivity, on investment, and vice versa.

Shapanka (1978) also explores technological changes in the energy sector in the context of I-O analysis (the SEAS/RFF model). More specifically, she identifies specific technological changes and modifies the corresponding I-O coefficients. In making these long-term projections, she relies on past trends and modifies these trends wherever necessary with expert judgment or information from technical and/or trade journals. The impacts of these technological changes in the coefficients are not reported in the Shapanka paper.

If these two studies are any indication, I-O analysis offers considerable potential for analyzing energy R&D. However, changes in the coefficients must first be linked to R&D expenditures. Just as important, the I-O table must be integrated into a macroeconomic structure. According to Behling, et al. (1977), Brookhaven National Laboratory is now using the Hudson-Jorgenson model in conjunction with BESOM to perform cost/benefit analyses of U.S. energy R&D programs. However, no results have yet been reported. (Behling, Dullien, and Hudson (1976) do present findings on the combined impact of energy R&D and a tariff.)

Miscellaneous Studies of Energy R&D

Although other studies examine energy R&D, none of them attempt to quantify the direct impact of energy R&D on the economy. For example, Greenwood and Jacoby (1975) discuss the international issues in ERDA-48 (see Energy Research and Development Administration (1975)). One of these issues concerns the world price of oil, a key energy variable with a substantial impact on the U.S. economy. According to Greenwood and Jacoby, ERDA carefully avoids arguing that its R&D efforts will influence the world price. Indeed, ERDA assumes a constant high oil price throughout its discussion. However, many people believe that the development and commercialization of new technologies will either lower world oil prices or limit future increases. Greenwood and Jacoby question this belief, arguing (p. 8) that an energy R&D program is "likely to have little effect on world price and could even lead to higher prices on international oil." They support this position with two arguments: (1) R&D-induced reductions in demand cause cartel members to raise prices to maintain revenue; and (2) R&D, by confirming the relatively high prices of alternative energy sources, makes cartel members realize they can charge higher prices. Judging from Greenwood and Jacoby's discussion (p. 12), the only positive influence of energy R&D on world prices comes from its signaling of "American determination to do something about energy dependence and to exercise leadership in the energy field...." But the OPEC member countries can counter this affect by undertaking their own R&D program, thereby reinforcing beliefs that the world is indeed running out of oil.

The Policy Study Group at MIT (1976) takes a more orthodox view of energy R,D&D (Research, Development and Demonstration). Noting first the

long-term nature of R,D&D programs, the Policy Study Group states that these programs will reduce imports and the costs associated with the transition to non-oil and non-gas energy resources. However, they never mention the impact of these changes on the economy. Instead, the Policy Study Group focuses on the possible distortion of incentives for private R,D&D, methods for correcting these distortions with government supported commercial demonstration programs, and general techniques for evaluating and planning commercial demonstration programs. Two of the most crucial ingredients to the R,D&D decision-making process appear to be the price of energy and the speed of diffusion of new technologies.

Peterka (1977) attempts to develop a mathematical model of market penetration by new technologies. Peterka emphasizes the macroeconomic view on the producer's side. He eliminates market price from his model by introducing market shares and then uses the model to study historical substitution (1920-1971) of primary energy sources in world energy consumption and to forecast market penetration by nuclear energy. However, the elimination of market prices and quantities of energy, and the rigid assumptions made about investment in alternative technologies rule out any interactions between the energy sector and the economy.

Other studies of energy R&D show a similar lack of concern with the macroeconomic implications of energy R&D. Searl and Perry (1974) consider the "idealized relationship" between the economic performance of technology and R&D cost. Tolley (1977) develops techniques for systematically selecting publicly supported R&D projects and then applies these procedures to energy storage projects. Five of the papers presented in the Tolley volume analyze the market penetration of new technologies. Biederman, et al.

(1975) assess private-sector funding of energy R&D. Rausser (1974) distinguishes between research innovation activities and so-called "learning-by-doing" activities and develops a model for production and development in the natural resource industries. Morrison (1978) explores the emerging "soft energy path" notion and relates it to soft or "appropriate technology" (AT). In a soft technology society, even questions about economic growth, productivity, etc., lose their relevance.

R&D and Economic Growth

With so little written on the impact of energy R&D on the economy, one must turn to the general literature on R&D. A National Science Foundation publication (1972) contains four commissioned papers (by Charles T. Stewart, Edwin Mansfield, William Fellner, and Zvi Griliches) summarizing the research into the relationships between R&D and economic growth/productivity. In a summary of these papers, Leonard L. Lederman answers (p. 3) the question: "What do we know about the relationship between R&D and economic growth/productivity?" as follows:

> Although what we know about the relationship between R&D and economic growth/productivity is limited, all available evidence indicates that R&D is an important contributor to economic growth and productivity. Research to date seeking to measure this relationship (at the level of the firm, the industry, and the whole economy) points in a single direction--the contribution of R&D to economic growth/productivity is positive, significant and high.

Stewart describes two approaches used to estimate the aggregate relationship between aggregate R&D and economic growth/productivity at the national level. Both approaches begin by subtracting quantitative growth (attributable to increases in factor inputs) from the total growth. The remainder or residual from this subtraction process presumably represents technological progress, part of which can be attributed to R&D. According

to Stewart, the "disembodied" approach to estimating this residual makes no allowance for improvements in quality of capital or labor. As a result, the residual--technological progress--accounts for up to 90% of total growth. On the other hand, the "embodied" approach attempts to incorporate changes in the quality of the inputs, thereby causing a substantial downward revision in the percentage of growth attributable to technological progress. None of the studies using either approach specifically isolates the contribution of R&D from the amalgam of factors contained in the residual. After surveying all of the evidence, Mansfield concludes (p. 23) that "technological change has certainly contributed in a very important way to economic growth in the United States." But he adds that, "it is clear that the state of the art in this area is not strong enough to permit us to make accurate estimates of the contribution...."

CONSERVATION REGULATIONS

Both supply and demand for energy are roughly price inelastic in the short-run. As a result, policy makers needing quick solutions to pressing energy problems may resort to direct intervention for conservation purposes, i.e., conservation regulations.

Conservation regulations can take a variety of forms. Probably the best known are the mandatory fuel efficiency standards for new cars established by the Energy Policy and Conservation Act of 1975. Other regulations include efficiency standards for buildings and mandatory burning of coal in utility boilers.

Energy-Economy Interactions

Although there are hundreds of articles on the microeconomics of energy conservation, there are only a few on the macroeconomic aspects. Moreover, most of these focus on price-induced conservation rather than on direct intervention for conservation.

Only Jack Faucett Associates (1975) provides direct estimates of the macroeconomic impact of energy conservation measures. Faucett analyzes eight different conservation measures including two direct interventions -- automobile design changes and improved energy efficiency in appliances. The macroeconomic impact of these conservation regulations is captured by changes in two aggregate indicators, GNP and the price level.

According to Faucett, the eight conservation measures taken together will reduce GNP by 1.4% by 1980, and energy consumption by 6.1%. The conservation measures would be "more deflationary than inflationary" (p. 41). The decline in GNP can be attributed to the following three factors:

- Direct cutbacks in final demand for energy products (.5%)
- Reduced demand because of price increases or income reduction (.4%)
- A multiplier effect generated by reduced consumer income (.5%)

All of these estimates are derived from figures supplied to Jack Faucett Associates by Peat, Marwick, Mitchell and Co. Appendix C of the Faucett study describes the calculations, but provides no breakdown of the impact by individual conservation measures.

Hudson and Behling (1978) also look at the impact of non-price conservation measures. These consist of prohibitions on large-scale industrial and utility uses of oil and gas and mandatory energy efficiency standards for end-use devices, including trucks and electric appliances. However,

Hudson and Behling lump these measures into a single "policy package" containing taxes on crude and refined oil and natural gas, subsidies and/or tax credits for capital expenditures, and government funding for demonstration projects. As a result, it is impossible to determine the effect of the conservation regulations.

The Federal Energy Administration (1977) uses the DRI macroeconomic model and PIES to examine the effect of the State Energy Conservation Program on GNP, on employment, and on the price level. The state program mandates thermal efficiency standards in all newly constructed commercial buildings. These standards would add approximately $2.7 to $2.8 billion (in 1975 dollars) to construction costs each year. According to FEA, the conservation measures will increase nominal GNP by $2.6, $4, $5.4, and $7.0 billion in 1977, 1978, 1979, and 1980. These figures correspond to percentage changes of .1, .2, .2, and .3%. Unemployment is .1% lower beginning in 1978 and the consumer price index is .1 to .2% lower during 1977 to 1980. The FEA findings on GNP contradict those of Jack Faucett Associates (1975). Apparently the FEA's surprising findings of an increase in GNP and employment stem from a real balance effect in the DRI model (caused by the slight decline in the price level).

Widmer and Gyftopoulos (1977) propose an Accelerated Energy Conservation Plan involving a number of conservation regulations designed to improve end-use efficiencies. Widmer and Gyftopoulos contrast the capital requirements for an economy without accelerated conservation (see Federal Energy Administration (1976)) with those associated with the Accelerated Conservation Policy. They claim that their policy would only cost a total of $218 billion for supply and conservation compared to $648 billion under

the FEA plan. Much of these savings stem from reductions in central station electric-generating capacity.

The only other studies even indirectly addressing the cost and benefits of conservation regulations are Hirst and Carney (1977), Seidel, Plotkin, and Reck (1973), and Hitch (1978). Hirst and Carney calculate the capital costs and the energy savings associated with appliance efficiency standards and thermal performance standards for new construction. These numbers may provide some guidelines for deriving macroeconomic impacts *á la* the Jack Faucett Associates approach. The Hitch book (1978), despite its very suggestive title of *Energy Conservation and Economic Growth*, never really relates conservation to growth. And Seidel, Plotkin, and Reck only offer some generalities about approaches to direct intervention.

CHAPTER VIII

ENERGY-ECONOMY MODELING

A CONCEPTUAL FRAMEWORK FOR ANALYZING ENERGY-ECONOMY MODELS

Brock and Nesbitt (1977), Gilbert, Jonish, and Taylor (1979), Charles River Associates (1979), and Hogan and Parikh (in Energy Modeling Forum (1977)) all examine the basic structure of energy-economy models.

Hogan and Parikh stress the need for a common framework for designing and comparing these models. They develop a framework based on the familiar view of the economy as a circular flow of products and resources, illustrated in Figure 8-1. Two groups of decision makers, producers and consumers, make all of the choices in this simplified economy. According to Hogan and Parikh (p. D-3):

> The producers utilize the resources of the economy (e.g., capital, labor, and energy) to make products (e.g., gasoline and food). These products can be classified as energy and nonenergy products, each of which is provided directly for consumers or utilized in other production processes. The consumers in turn provide the economic resources to the producers and demand their products. The demands of consumers may be for energy or nonenergy products and there is an interaction between these components.

Since the demand and supply for resources and products must balance, each model of energy and the economy contains some mechanism (either implicit or explicit) for achieving this balance. Indeed, some of the most fundamental differences in the models arise from alternative ways of meshing demand and supply.

Hogan and Parikh base their comparison of energy-economy models on certain features of the producing and consuming sectors and on the balancing mechanisms. According to them, these models uniformly organize

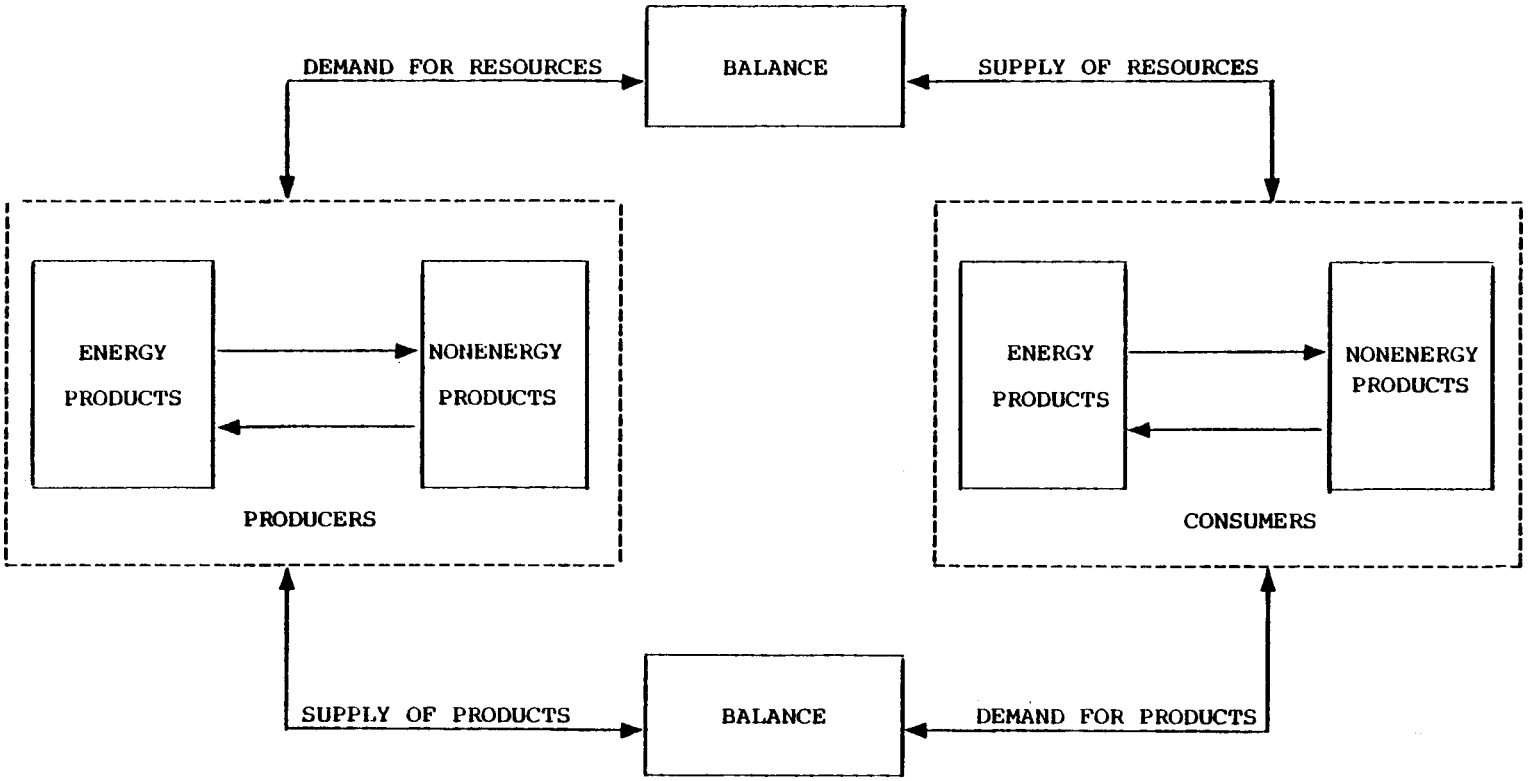


Figure 8-1. Flow of Products and Resources in the Economy

Source: Energy Modeling Forum (1977, p. D-2).

the production sector around an interindustry input-output structure with energy used as an intermediate good in the manufacturing process. Despite this similarity, energy-economy models differ in a number of aspects. Hogan and Parikh single out the level of aggregation, the degree of substitution, the representation of dynamics, and the incorporation of trends for special attention. Here are their comments (p. D-3 to D-5) on each of these features:

> Aggregation. All the models distinguish between energy and nonenergy products, but the level of further disaggregation varies from none to a separate representation and accounting for more than 50 industrial groupings.
>
> Substitution. A key element in the measurement of the feedback from the energy sector to the economy is the assessment of the flexibility of energy utilization in the production system of the economy. This flexibility can be broadly classified into two components: interfuel substitution and factor substitution.
>
> Dynamics. All the systems deal with the evolving economy in a dynamic framework, but the underlying dynamic structures differ among the models. Two attributes may be used to describe the differences across models: interaction of variables and speed of adjustment. The interaction of variables may be myopic, with current decisions determined entirely by current parameter values, or clairvoyant, with current decisions determined simultaneously by all parameter values. The dynamics of a model might permit instantaneous adjustment in variables resulting from exogenous shocks, or the adjustment may be gradual.
>
> Trends. All of the models deal with some important exogenous parameters and structural changes through the application of simple trends. In this context, it is possible to define a standard set of variables that determines the long run growth of output in absence of any bottlenecks. This standard set consists of time profiles of population, labor force, and labor productivity.

The models also differ in their balancing mechanisms. These balancing mechanisms can be categorized as satisfying either a positive or normative objective. A positive objective corresponds to a market equilibrium with producers all assumed to maximize profits and consumers to maximize utilities. On the other hand, the normative objective corresponds to the assump-

tion that producers and consuming sectors cooperate to maximize some joint criterion function. The balancing mechanism can also be viewed in terms of dynamics. Like the producing and consuming sectors, a balancing mechanism can be either myopic or clairvoyant.

Charles River Associates (1979) recently completed a critical review of more than a dozen energy models. Unlike the Energy Modeling Forum report by Hogan and Parikh, this study includes not only energy-oriented macroeconomic growth models, but also interindustry models, energy-sector models, and models of individual energy industries. Unfortunately, the Charles River Associates study does not include an explicit conceptual framework for comparing and analyzing energy models. This absence of a conceptual framework, together with the large number of diverse models included in the survey, makes it difficult to comprehend the important features of the models.

Charles River Associates does include a simplified illustration of energy-economy interactions. These interactions are shown in Figure 8-2. Judging from this diagram, the principal interactions between the energy and the economy are as follows:

- Prices of primary energy and energy products affect prices and costs throughout the economy.
- Levels of income and energy-using industrial activity affect the levels of demand for energy products.
- Prices of primary factors and intermediate good inputs to energy supply and use affect the cost of supplying and using energy.

Charles River Associates (1979), Gilbert, Jonish, and Taylor (1979), and Brock and Nesbitt (1977) all mention a number of ways to distinguish between different energy-economy models. Charles River Associates be-

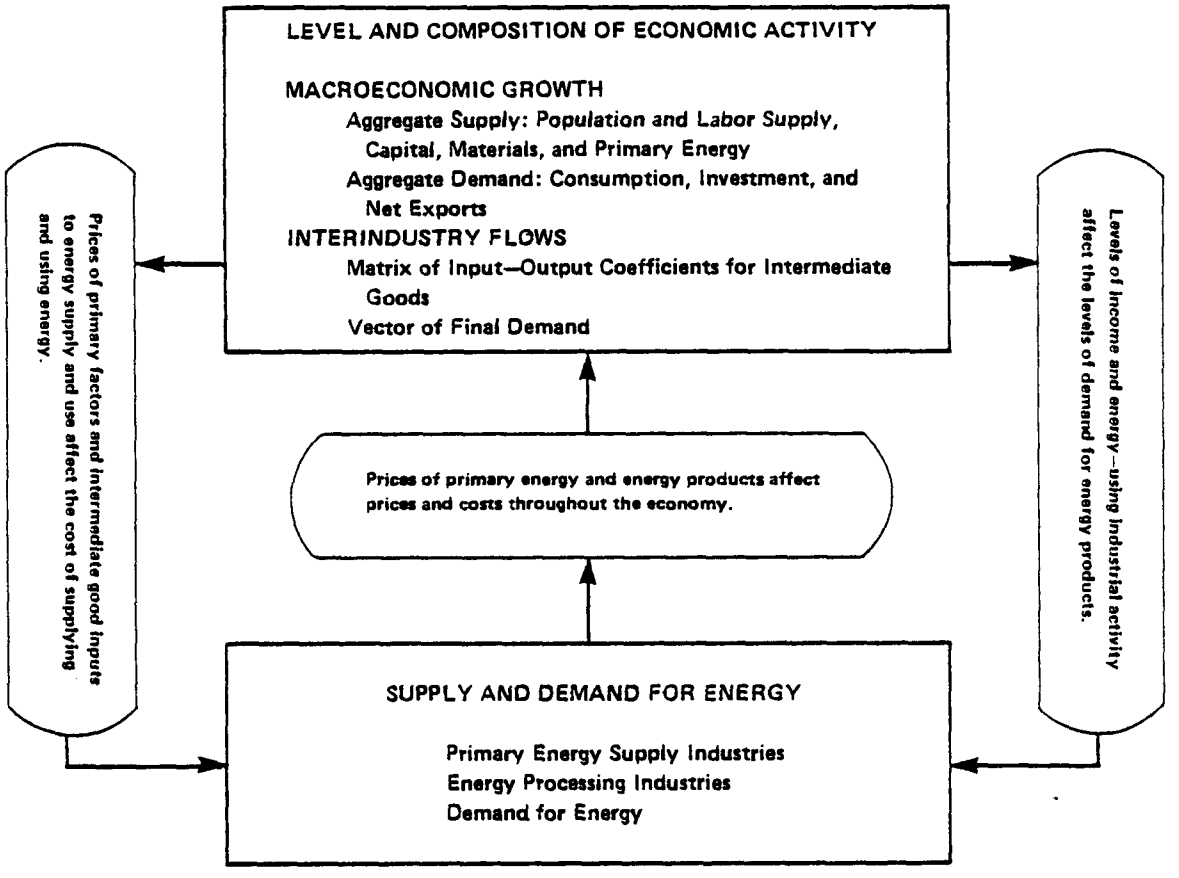


Figure 8-2. Simplified Illustration of Energy-Economy Interactions

Source: Charles River Associates (1979, p. S-3).

lieves (p. 2-2) that "The important distinctions in macroeconomic specification concern post-Keynesian versus neoclassical formulations, and the nature of the linkage between macroeconomic specifications and energy supply or demand." The post-Keynesian models are demand-oriented. They do not include a complete specification of the supply side of the economy. The neoclassical models include both the supply and demand sides. They emphasize the role of production, supply behavior, and price relationships. These structural differences reflect the different purposes of the post-Keynesian and neoclassical models. The post-Keynesian models are generally used to focus on short-run forecasts, the neoclassical models on long-term economic growth.

The issue of linkages is especially important to the modeling of energy-economy interactions. During the last five or six years energy modeling has progressed through several phases. Macroeconomic models were originally employed simply as a source of exogenous forecasts of aggregate economic variables. These forecasts were then used to derive growth rates for the energy sector. The OPEC embargo and the ensuing energy crisis created a sudden need for analyses of the impact of energy-sector changes. This need was met by establishing a weak linkage between large-scale macroeconomic models and models of the energy sector. For example, the Department of Energy uses its PIES model to project energy prices and quantities. These projections then serve as exogenous variables in the DRI macroeconomic model. Now a "third generation" of models like the Hudson-Jorgenson, ETA-MACRO, and Wharton Annual Energy models are appearing with a formal linkage providing for interactions between the energy sector and the economy.

In their analysis of large-scale energy planning models, Brock and Nesbitt (1977), focus on the different methodologies embodied in five well-known models. These methodologies consist of variable coefficient input-output theory and the translog theory, the concept of equilibrium in a spatial network in linear programming, nonlinear optimization, and system dynamics.

Like Hogan and Parikh, Brock and Nesbitt also differentiate between descriptive and normative modeling. They state (p. I-13) that "In appraising the descriptive [as opposed to the normative] capabilities of large scale models, the important question is: How well does a given model represent the underlying quasi-hierarchial decision system...?" Brock and Nesbitt then break this question down into two subquestions: (1) "How well does the model represent the underlying physical system"; and (2) "How well does the model describe the decision making behavior of the... citizens?"

The modeling of the physical system involves three sets of considerations:

- Technological detail concerns the degree to which a given model captures the various technological features of the system.
- Aggregation in modeling is resorted to because of informational considerations. There are various types of aggregation which arise in energy models: geographical aggregation, aggregation by "type" of producer and consumer, and aggregation by type of technology.
- "Sectoral comprehensiveness" refers to the degree to which a given energy model takes account not only of the energy sector of the economy but of the effects of the other sectors.

In contrast to their detailed discussion of physical systems modeling, Brock and Nesbitt never really explain what they look for in behavioral modeling. Most energy planning models appear to incorporate "rational

choice" assumptions, i.e., consumers act to maximize utility and producers to maximize profit. Moreover, all of these models use microeconomic analysis. Brock and Nesbitt also say little about normative modeling, other than to emphasize (p. I-20) that the models reviewed "are not always directly pertinent to policy analyses which have a normative orientation...."

In their examination of the role of energy in the U.S. macroeconomic models, Gilbert, Jonish, and Taylor (1979) note that energy-economy models can be compared in terms of their sectoral detail (energy and non-energy), substitution possibilities (both in production and consumption), and their dynamic adjustment processes.

Conceptual Framework Used in this Survey

Planco has developed its own conceptual framework for analyzing models of energy-economy interactions. (None of the studies cited in this section were available at the start of our survey for the Department of Energy.) Unlike previous analyses, our framework provides for explicit recognition of the principal components of energy-economy models. These components represent the structure of the energy sector, the structure of the U.S. economy, and the macroeconomic structure.

The energy sector supplies energy to the economy. The activities in this sector can be characterized as involving either the extraction of primary energy resources such as oil and gas, or the conversion and distribution of energy. The energy resources can be classified as oil and gas, coal, uranium, and other (oil shale, tar sands, etc.). Energy conversion and distribution consists of refining and oil distribution, electric utilities (including nuclear), gas utilities and distribution, liquefaction and

gasification, and solar. Some of the most crucial issues involved in the modeling of these activities concern capital requirements and costs, energy products and their prices, and interfuel substitution.

The second basic component of energy-economy models consists of a model of the structure of the U.S. economy. This model describes the demand for energy. Energy is somewhat of a unique good. The demand for energy is an intermediate (derived) demand. This derived demand can best be characterized by the supply in the non-energy sectors of the model, i.e., by the structure of the U.S. economy.

The energy-economy models differ in their level of aggregation of the economy. All of the models use either an input-output table or an aggregate production function. Some obvious questions about the level of aggregation include: How many non-energy sectors are there in the model? Is there a derived demand for energy in each of the non-energy sectors? Is energy disaggregated by categories (electricity, industrial heat, residential heat, substitutable transportation, and non-substitutable transportation)? The energy-economy models also differ in the assumptions made about the factors of production (capital, labor, energy, and materials). For example, what assumptions are made about different vintages of capital, stock adjustment, etc.?

Another area of great importance to both model builders and users involves substitution possibilities between various factors of production. Too many studies ignore or understate the possibility of substitution between energy and other factor inputs as prices and/or supplies change. These studies seriously overstate the impact of supply changes (with fixed proportions, a cutback in energy provokes a proportional change in output)

and understate the impact of price changes.

The final component of energy-economy models, and the one most often ignored, is the macroeconomic structure. The macroeconomic structure represents the aggregate demand for final goods. (The structure of the U.S. economy explains the supply of final goods, and at the same time the derived demand for energy.) Final demands for goods can be disaggregated into four major categories: investment, consumption, government spending, and international trade (imports and exports). When present, the macroeconomic structure is generally represented by a growth model. This growth model may incorporate inflation, capacity utilization, unemployment, asset markets, wealth, rate of interest, money, etc.

Table 8-1 shows the conceptual framework used by Planco to analyze energy-economy models.

ENERGY-ECONOMY MODELS

With a conceptual framework for the study of energy-economy interactions in place, it is time now to turn to actual models of energy-economy interactions. Just what constitutes an energy-economy model? Meaningful definitions or categorizations depend upon a conceptual framework, as the long and often contentious debate about the proper definition of money (is it M1, M2, or M3?) demonstrates. We define an energy-economy model as an integrated "system" consisting of three structures: the structure of the energy sector, the structure of the U.S. economy, and the macroeconomic structure. Only four models <u>currently in operation</u> satisfy this definition: Hudson-Jorgenson, Manne ETA-MACRO, Wharton Annual Energy Model, and PILOT. (We exclude the DRI Energy Modeling System from

TABLE 8-1

PLANCO'S CONCEPTUAL FRAMEWORK FOR THE SURVEY OF MODELS OF ENERGY-ECONOMY INTERACTIONS

I. Introduction

A. Principal developers
B. Type of model and submodels
C. Complexity
D. Sectors emphasized
E. Time horizon
F. Questions addressed
G. History and use

This overview provides a brief description of the model, its unique features, and its purpose(s).

II. Energy-Economy Interactions

A. Direct
B. Indirect

Model builders seldom explicitly state the energy-economy interactions in their models. Indeed, some may even be unaware of these interactions. The taxonomy of energy-economy interactions described in Table 1-1 can be used to summarize these relationships. For example, the model might incorporate interactions between energy and GNP, the unemployment rate, and the CPI.

III. Structure of the Energy Sector

A. Overview
B. Energy Resources, extraction costs, and scarcity rents
   1. Oil and gas
   2. Coal
   3. Uranium
   4. Other (oil shale, tar sands, etc.)

What assumptions are made about supply, costs and capital requirements of each of the energy resources? What modeling techniques are used, i.e., econometrics, process analysis, mathematical programming, input-output analysis?

C. Energy conversion and distribution, capital requirements and costs
   1. Refining and oil distribution
   2. Electric utilities (including nuclear)
   3. Gas utilities and distribution
   4. Liquefaction and gasification
   5. Solar

Table 8-1--Continued

What assumptions do the model builders make about costs and capital requirements of energy conversion and distribution?

D. Energy products and their prices
E. Interfuel substitution

IV. Structure of the U.S. Economy

The distinction made here between the demand for final goods and the demand for energy is an important one which has been largely overlooked in previous surveys. Energy is somewhat unique. The demand for energy is an intermediate (derived) demand and can best be categorized by the supply in the non-energy sectors of the model, i.e., by the structure of the U.S. economy.

A. Level of aggregation
   1. Production function
   2. Input-output table

How many non-energy sectors are there in the model? Is there a derived demand for energy in each of the non-energy sectors? Is energy disaggregated by categories (electricity, industrial heat, residential heat, substitutable transportation, non-substitutable transportation).

B. Factors of Production
   1. Capital

How is capital handled in the model? What assumptions are made about vintage, stock adjustment, etc.?

   2. Labor
   3. Energy
   4. Materials

C. Substitution possibilities (elasticities)

V. Macroeconomic Structure

A. Determinants of investment
B. Determinants of consumption
C. Government spending
D. International sector

How does the model incorporate the international sector, especially imports, exports, and the balance of payments?

E. Inflation, capacity utilization, and unemployment
F. Asset markets, wealth, and the interest rate
G. Money and other

Table 8-1--Continued

VI. Growth and Technical Change

A. Demographics
B. Capital stock adjustment
C. Technical change and productivity
D. The real rate of return to capital

VII. Method of Solution

A. Balancing equations
B. Solution techniques

VIII. Evaluation of Model

A. Capabilities

The reviewers provide detailed comments on the models' strengths and weaknesses in this section. They also address the possible linkages with other models and/or modifications which could be made in the model to specifically address energy-economy interactions.

B. Uses
C. Policy levers

The question of policy really relates to the structure of the model. For that reason, this section explores both the options available to potential model users and those already explored by the builders of the model.

this category because of the complete absence of supporting documentation.) Of these four, the Hudson-Jorgenson and ETA-MACRO models are the best documented and most frequently exercised. The Wharton Annual Energy Model has recently undergone extensive revision and may soon see more use. The PILOT model, also in a state of revision, has been judged by EPRI to be of limited usefulness in analyzing energy-economy interactions.

A number of other models have been used in the study of energy-economy interactions. Hitch's book (1977) on Modeling Energy-Economy Interactions: Five Approaches includes the RFF/SEAS model, a two-sector model by Reister and Edmonds, and a conceptual model by Hogan and Manne. The Energy Modeling Forum (1977) bases its examination of the links between energy and the economy on six models: Hnyilicza, Kennedy-Niemeyer, DRI-Brookhaven, as well as the Wharton, PILOT, and Hudson-Jorgenson models.

Our survey of the literature and an informal poll of energy modelers originally suggested additional candidates for the class of energy-economy models including:

- DRI
- SRI-Gulf/LEEM
- PIES
- WAES
- Dartmouth Systems Dynamics Model
- Bechtel Energy Supply Planning Model
- Berkeley (Glassey and Benenson) Model
- SIMRICH/OECD
- University of Illinois Energy Accounting Input/Output Model
- World Energy Model

- LORENDAS
- LEAP
- COAL-1
- International (OECD) Energy Demand Model
- Carter
- Just
- Nordhaus Bulldog

Altogether there are a total of twenty-eight potential energy-economy models.

But these large numbers are misleading. Model building epitomizes the Darwinian struggle for survival. Because of the high cost associated with large-scale energy models, their survival depends on the sometimes whimsical decisions of funding agencies. Moreover, evolution takes place very quickly in the energy modeling discipline. Model builders either continually update their models or watch as rapid technological change makes them obsolete and/or irrelevant.

Several excellent "energy-economy" models are no longer operational, judging from the personal comments of the model builders and/or the absence of any current reports. These models include the Hnyilicza, Kennedy-Niemeyer, SIMRICH/OECD, and Berkeley (Glassey-Benenson) models. Others never were operational, existing solely as theoretical constructs. These include the Reister-Edmonds and Hogan-Manne models.

Other models, although currently operational, fail to satisfy our definition of an energy-economy model as an <u>integrated</u> system depicting the energy sector, the structure of the economy, and the macroeconomic structure. These other models can be grouped into three categories -- energy sector, interindustry, and macroeconomic -- with each category representing one

of the components of a complete energy-economy modeling system. Table 8-2 lists the models and gives detailed references.

METHODOLOGIES

The structure of the U.S. economy can be described in two ways: with an input-output table or with a production function. Despite the difference in appearance, the production function and I-O table both serve the same purpose. They summarize the technological relationship between inputs and outputs (products). By doing so they make it possible to derive the demand for different inputs like energy. Model builders opting for the aggregate production function (like Hnyilicza, Kennedy-Niemeyer, and Manne) sacrifice the detail possible with an I-O table. But they greatly simplify their task. Moreover, the aggregate production function makes it possible to directly model substitution possibilities, investment, and technical change.

On the other hand, three of the four major energy-economy models -- Hudson-Jorgenson, Wharton, and PILOT -- use I-O tables to depict the U.S. economy. Each year the I-O tables used in these models grow larger and larger. The Hudson-Jorgenson model started with nine-sectors, then went to ten-sectors, then merged with the Brookhaven BESOM linear programming model, then combined with the 110-sector Brookhaven-Illinois Input-Output Model. The latest round of funding appears to be directed at still further increases in size as technology and capital are incorporated into some of these models.

A variety of methodologies underlie the I-O tables used in the energy models. Griffin (1976) gives the single best discussion of these differ-

TABLE 8-2

REFERENCES FOR ENERGY SECTOR, INTERINDUSTRY, AND MACROECONOMIC MODELS

Name of Model	References
Baughman-Joskow	Baughman-Joskow (1975)
Bechtel Energy Supply Planning Model	Carasso, Gallagher, and Sharma (1974), Carasso, et al. (1975), Gallagher, et al. (1978), Gallagher and Zimmerman (1976, 1978)
Brookhaven National Laboratory/ BESOM, DESOM, TESOM	Behling (1976, 1977), Behling, et al. (1977), Behling and Dullien (1976), Behling, Dullien, and Hudson (1976), Cherniavsky, Juang, and Abilock (1977)
Carter	Carter (1974)
Coall	Naill (1976)
DFI	Adler, et al. (1978)
DRI Economic/Energy Modeling System	Data Resources Inc. (forthcoming)
DRI (Verleger) Energy Model	Verleger (1974), Williams (1976), Data Resources Inc. (1976)
DRI Macroeconomic Model	Askin (1978b), Askin, et al. (1977) Farman and Lagace (1978), JRB Associates (1978), Sinai and Brinner (1975), Eckstein (1978)
Dartmouth Systems Dynamics Model	Choucri, Ross, and Meadows (1976), Naill (1976)
ETA-MACRO	Adar and Manne (1977), Arnoldy and Cavallo (1977), Hamilton and Manne (1977), Manne (1976, 1977), Manne and Richels (forthcoming), Schmitt, BenDaniel, Stewart, and Manne (1977)
Glassey-Benenson	Glassey and Benenson (1975a, 1975b, 1975c), Merrill, Lofting, and Quong (1974)
Hnyilicza	Hnyilicza (1975, 1976)

Table 8-2--Continued

Name of Model	References
Hudson-Jorgenson LITM	Behling (1976, 1977), Behling, et al. (1977), Behling and Dullien (1976), Behling, Dullien, and Hudson (1976), Bernanke and Jorgenson (1975), Cogan, Johnson, and Ward (1976), Hoffman and Jorgenson (1977), Hudson and Behling (1978), Hudson and Jorgenson (1974, 1976a, 1976b, 1978a, 1978b, 1978c), Dullien (1976), Goettle, Cherniavsky, Tessmer (undated), Jorgenson (1976)
INFORUM	Almon, et al. (1974), Almon and Nyhus (1977)
Illinois Input-Output Model	Behling, Dullien, and Hudson (1976), Bullard, Hannon, and Segal (1976), Bullard and Sebald (1975)
Just	Just (1974), Just, et al. (1975)
LORENDAS	Boudrye, et al. (1977)
Nordhaus Bulldog	Nordhaus (1973, 1976b, 1977a, 1977c, forthcoming)
PIES	Askin (1978b), Askin, et al. (1977), Hogan (1977b), M.I.T. Energy Laboratory Policy Study Group (1975)
PILOT	Barzelay (1977), Connolly, Dantzig, and Parikh (1977), Dantzig (1975a, 1975b), Dantzig, Connolly, and Parikh (1978), Dantzig and Parikh (1976, 1977a), Parikh (1976, 1977), Parikh, Braun, and Yu (1978), Weyant, Buras, and Swift (1978)
Penn	Penn and Irwin (1977), Penn, McCarl, Brink, and Irwin (1976)
RFF/SEAS	Ridker and Watson (forthcoming), Ridker, Watson, and Shapanka (1977), Shapanka (1978)
Reister and Edmonds	Reister and Edmonds (1977)

Table 8-2--Continued

Name of Model	References
SIMRICH-OECD	Gunning, Osterrieth, and Waelbroeck (1976)
SRI-Gulf (and Livermore Energy Policy Model)	Cazalet (1977), Kopelman and Nesbitt (1977), Rambo and Coles (1978), Rousseau, Rambo, Castleton, and Sussman (1978), Rousseau, Sussman, Castleton, and Rambo (1978), Stanford Research Institute (1976a, 1976b, 1977), Stern and Cooper (1978), Sussman and Rousseau (1978a, 1978b), Thompson, et al. (1978)
WAES	Basile and Sternlight (1977), Wilson (1977)
Wharton Annual Energy Model	Duggal, Klein, and Schink (undated), Griffin (1977), Library of Congress (1978), Wharton E.F.A. (1978), Wharton Econometric Forecasting Associates (undated)
Wharton Macroeconomic Model	Askin (1978b), Askin, et al. (1977), Malloy (1978), Preston (1975), Klein (1976)
World Energy Model	Deam and Leather (1974)

ent techniques. Paraphrasing Griffin, the various energy I-O methodologies can be categorized as follows:

- Fixed coefficient
- Fixed coefficient with linear programming optimization
- Flexible coefficient based on process analysis
- Flexible coefficient based on econometrics
- Flexible coefficient based on econometric/process analysis

Griffin uses the words "static" and "dynamic" in place of "fixed" and "flexible coefficient." Dynamic usually refers to an input-output system involving lags or rates of change of variables over time (usually reflecting investment) and it will be used here in that same context.

Probably the best known example of fixed coefficient I-O analysis is provided by the Illinois Center for Automated Computation (CAC) I-O model. The Illinois model consists of a very large I-O table, 367 industries. The coefficients in the model are expressed in terms of BTUs rather than dollars. This conversion to a physical output measure like BTUs overcomes several shortcomings in the more traditional formulation in dollar terms. In particular, if the price of energy inputs differ from sector to sector, then the conventional I-O coefficients, instead of remaining constant, depend upon the mix of sales. This is because the value of energy production varies depending upon whether it is sold to a high-priced use or a low-priced use. Do energy prices actually vary over different industries? According to Griffin (1976), the answer is yes -- very substantially.

Nonetheless, potential users of energy I-O analysis need to be aware of its shortcomings. Griffin (1976) and Glassey and Benenson (1975a) review

the potential data and methodological problems of this type of analysis. Four problem areas are related to the data used in constructing the I-O tables. First, no distinction is made between imported and domestic goods. This aggregation of domestic and foreign goods produced with different technologies biases the coefficients. Second, the I-O data are collected by establishment rather than by a specific product. Third, the energy embodied in the capital used in the production of goods is not reflected in the energy coefficients. Fourth, the energy and quantity data used to calculate inputs in BTU-related units may not be adequate. The methodological problems associated with energy I-O analysis include aggregation bias and instability in the I-O coefficients. In addition to the problems of incorporating energy explicitly into I-O tables, there are numerous limitations to I-O analysis in general. Glassey and Benenson (1975a) give an excellent summary of these limitations.

Bullard and Herendeen exercise the Illinois I-O model in a variety of applications. They calculate the energy cost of an average car, where that cost includes both the energy used directly in fuel and the energy used indirectly in the manufacture and retail of the car, repairs, tires, highway construction, etc. They contrast the employment and energy effects of alternative government programs, showing both energy and employment intensities. And they compute the energy content of imports and exports. Griffin comments (p. III-2) that this "preoccupation with counting BTUs reminds economists of the labor theory of value" with energy now replacing labor. This preoccupation "masks the really vital issue of interfuel substitution possibilities." Griffin goes on to say that "the major contribution of energy I-O coefficients is to trace the flows of

various fuels so that major possibilities for interfuel substitution can be isolated and studied."

The fixed coefficient I-O table suffers from one overwhelming shortcoming -- extreme rigidity. In particular, the fixed coefficients make no allowance for either interfuel or factor substitution. Therefore, energy-economy models based on fixed coefficient I-O tables should never be used for intermediate or long term projections. (Unfortunately, model builders too often ignore this fact of economic life.) Much of the effort in energy-economy modeling has gone toward incorporating substitution possibilities into I-O models. These efforts are discussed next.

Fixed Coefficients with Linear Programming Optimization

The fixed coefficient I-O tables are sometimes combined with linear programming optimization. Brock and Nesbitt (1977) provide a detailed review of linear programming techniques. According to them, the energy allocation process can be described by the Koopmans-Hitchcock-Kantorovich transportation problem. The linear programs used in the various energy models consist of four basic elements -- technology, located fuels, supplies, and demands. Although the technologies are linear, i.e., fixed proportions, substitution can be modeled by including several different technologies for the same product. The located fuels can be interpreted as the total quantity of a specific type of fuel available in a given geographical region. The supplies are the energy resources and are described by the maximum quantities available at a specific point in time. The final demands are specified outside the model and represent minimum demands that must be satisfied. The final ingredient in the linear program is a set of costs associated with the various technologies. Given the technologies,

costs, constraints on supply and demand and material balances, the linear programming procedure finds the set of production levels which minimizes the total cost of providing energy. The Brookhaven models and PIES probably provide the best examples of using linear programming to solve for a set of cost-minimizing energy flows.

The coupling of linear programming with I-O analysis can take several forms. In the PILOT and Berkeley models a linear program "drives" the overall model by maximizing final demands. The linear programming technique can also serve to modify the production process implied by the I-O table. Glassey and Benenson (1975a, 1975b) attempt to increase the flexibility of their model by expanding the I-O table to include different technologies for the electric utility and iron and steel industries. The Illinois input-output model has been linked with the Brookhaven linear programming energy model. The Brookhaven model minimizes the cost of meeting energy demands. These solution values are then used to compute the technical coefficients characterizing the energy sectors in the Illinois input-output model.

Variable Coefficients Based upon Econometrics and/or Process Analysis

The coefficients in the Hudson-Jorgenson interindustry model depend upon the relative prices of the factors of substitution. As Dhrymes and others point out (see Khazzoom (1976)), this is a major innovation. Although the Hudson-Jorgenson procedure for estimating these coefficients has been described in a number of places (Griffin (1976), Brock and Nesbitt (1977), Charles River Associates (1979), and Khazzoom (1976)), Hudson and Jorgenson's treatise for the General Services Administration (1978c) serves as the ultimate reference. Hudson and Jorgenson note that their

basic result is the derivation of the variable (flexible) input-output coefficients with the following relationship:

$$\frac{P_{ij} * X_{ij}}{P_j * X_j} = \frac{\partial \ln P_j}{\partial \ln P_{ij}}$$

where P_{ij} = price of output of sector i purchased by sector j,

P_j = average price of output from sector j,

X_{ij} = quantity of input from sector i to sector j,

X_j = total quantity of output from sector j.

Hudson and Jorgenson base their estimates of the input-output coefficients upon a translog price possibility frontier. This function is quadratic in the logarithms of input prices and output quantities.

The Hudson-Jorgenson approach to introducing flexibility into the I-O coefficients creates some problems. Indeed, Kuh (see Khazzoom (1976), p. V-3) has "reached a tentative conclusion that, in its current state, certain substantive issues should be resolved before the translog is used for serious policy analysis." Kuh has three reservations about the translog function. First, the underlying theory assumes long-run equilibrium, thereby ignoring all cyclical fluctuations in dynamic adjustments. However, some preliminary tests conducted by Kuh with a capacity utilization variable reflecting cyclical fluctuations contradict this assumption. Second, strong economic assumptions about constant returns to scale, symmetry, and convexity must be imposed in order to estimate the large number of parameters. Again, there is a question about the validity of these assumptions. Third, the historical data appear to be grossly inadequate for estimating the translog production function, which in turn appears to be inadequate for exploring substantial shifts in relative energy prices

(since the translog is only a second order approximation). These criticisms of the translog function and others are reviewed in more detail in Chapter X.

The Wharton model also uses flexible input-output coefficients. The Wharton group bases their estimates of the I-O coefficients on econometric estimates of a constant elasticity of substitution production function and a time trend. The time trend makes it possible to assume partial adjustment to changes in factor prices.

The Wharton group also use process analysis to derive some of the I-O coefficients. Judging from Griffin's description (1976), the Wharton approach differs substantially from that used by Brookhaven. First, a linear programming model is used to generate optimal combinations of inputs for different sets of assumed input prices. These observations on input prices and corresponding input quantities provide the "pseudo-data" needed to fit a statistical cost function. Once the cost function has been estimated, the production function can be recovered from the cost function and the input-output coefficients calculated. Although this approach sounds very promising, the complete lack of documentation makes it impossible to validate this methodology.

STATE OF THE ART OF MODELING ENERGY-ECONOMY INTERACTIONS

On January 29 and 30, 1976, nearly fifty distinguished economists and energy specialists gathered together at an EPRI Workshop on Modeling the Interrelationships between the Energy Sector and the General Economy. The proceedings of this workshop (1976) probably qualify as the single most important contribution to the literature on energy-economy interactions.

The session chairman, J. Daniel Khazzoom, provides an excellent summary of the state-of-the-art of energy-economy modeling as perceived by the members of the workshop. Since EPRI's purpose for holding the workshop was to identify research and data needs, the participants' primarily addressed the current limitations to energy-economy modeling. Khazzoom sets the tone for their comments when he says (p. I-8) that:

> Models that focus on the interrelationships between the energy sector and the rest of the economy have existed for less than half a decade; consequently, the development of such models is still in its infancy. Unfortunately, modelers have failed to stress forcefully enough the limitations of these early efforts.

Khazzoom summarizes six major drawbacks to the models. They are as follows:

- Preoccupation with equilibrium analysis.
- Tendency to rely exclusively on only one methodology.
- Inadequate representation of technology in input-output models.
- Tendency to focus on one policy to the exclusion of alternative policies.
- Tenuous and ambiguous nature of the feedback process between the energy sector and the economy.
- Inadequate validation procedures.

According to Khazzoom, most of the published models are based upon general equilibrium analysis. But in reality, the energy market typically lacks equilibrating forces because of regulatory interventions such as taxes, price controls, average pricing schemes, and the dependence on cartel-determined prices. As a result of these wedges between prices and costs, producers and consumers do not respond to equilibrium prices as assumed in the models. Moreover, the static models force supply to equal demand when in fact serious shortages have existed in natural gas and to

a lesser extent other energy sources for years. The models also typically fail to take account of institutional realities such as the dynamics of resource exhaustion and the adjustment process, the distributive effects of various policy measures, and a variety of so called "non-quantifiables."

Most energy models also rely upon one of two methodologies--econometrics or optimization. The parameters of the econometric model are generally estimated with pre-embargo time-series data. These data depict an apparently by-gone era of steadily declining real energy prices. Many of the workshop participants questioned whether models based upon such data could safely be used to forecast behavior with prices 300% to 500% higher. Certainly there is no reason to assume that the substituion process between energy and other factor inputs is both reversible and occurs at the same rate as in the past.

A number of model builders attempt to escape the chains of the past by basing their models upon optimization techniques, usually in the form of I-O analysis. However, these I-O tables also suffer from data limitations. Moreover, many of these I-O tables consist of fixed coefficients, thereby unrealistically implying fixed technologies. Different technologies can be introduced by making the coefficients vary with either input prices or time, but the accurate estimation of I-O coefficients as a function of input prices requires more data than are available (because of the large number of parameters and the small number of input-output tables). And making the coefficients a function of time requires some strong assumptions about future technologies which may or may not be feasible.

A fourth limitation in energy-economy modeling is a tendency to focus on a small number of policy alternatives. Another shortcoming involves

the tentative nature of the interrelationships between energy and the economy. And a final major weakness lies in inadequate validation procedures, a topic discussed at greater length in the next section.

The workshop participants also devoted considerable time to discussing the inadequacy of data, judged by many to be the single biggest problem for energy modeling today. Khazzoom lists the following major weaknesses in the data:

- Data availability is a major problem. Serious data gaps exist in such critical areas as equipment stock characteristics except for automobiles, utilization rates for individual appliances, energy efficiency of equipment, etc.
- Often data are available, but the form in which they are available is not suitable for direct incorporation in economic models. An example is the engineering data on energy technology.
- The inconsistency of the existing data--whether they are published by the same agency or by different agencies--can cause serious problems. Inadequate documentation compounds the difficulty.
- There are no systematic surveys by collecting agencies to determine what data still need to be collected.
- Sometimes the data needed for energy modeling cannot be compiled with a high degree of accuracy, given the state of the art of other fields.

Khazzoom concludes by saying (p. I-16) that "the present state of energy data offers a monumental task to modelers interested in credible results."

Model Documentation and Validation

Judging from the comments of the EPRI workshop participants, the current energy models suffer from a lack of credibility. (Perhaps this credibility gap exists only among the better informed. For a contrasting view see a Fortune article by Cameron titled "The Economic Modelers Vie for Washington's Ear (1978)). This lack of credibility stems from a failure

to validate the models.

The key to validation is independent replication of the model's results. But this replication requires detailed documentation and sometimes expensive duplication of research efforts. Documentation is an especially critical area. Even the widely-used models possess black-box properties because of their lack of detailed documentation.

Another EPRI workshop (see Dantzig and Parikh (1977b)), this one to consider a forum for the analysis of energy options through the use of models, also resulted in a call for better documentation by nearly every speaker. According to the proceedings of the forum workshop (p. III-5), "The existence, timeliness, completeness, readability, dissemination, and purposes of most documentation were challenged or criticized by the workshop participants."

The comments of participants at a Massachusetts Institute of Technology (1975) Workshop on Modeling Large Scale Systems echo those of other workshops. In particular, there was general agreement on the need for greatly improved documentation of models. Workshop participants also discussed the validation of models. Present validation procedures were found to be seriously wanting.

Apparently all of these pleas for improved documentation and validation have had some impact on funding agencies. According to Greenberger (1977), EPRI established the Energy Modeling Forum in 1976 to promote interaction between decision makers and model builders. The designers of the Forum project provided for a strong user orientation. The Forum's functions include the use of major energy models, dissemination of the impacts of various energy options, the identification of critical elements

and strengths and weaknesses of existing models, the provision of guidance for the improvement, linkage, and extension of energy models, and the establishment of priorities for new modeling research.

The Energy Modeling Forum's first project (1977) involved the use of six models -- DRI-Brookhaven, Hnyilicza, Hudson-Jorgenson, Kennedy-Niemeyer, PILOT, and Wharton -- to investigate the feedback from the energy sector to the economy. Its second undertaking (1978) consisted of a comparison of the projections from ten energy models of total coal production for the period 1980 to 2000.

EPRI also sponsors a model validation laboratory at MIT. The MIT group has just completed a validation study of the Wharton Annual Energy model and the Baughman-Joskow model and plans to issue a report (1979) in the near future. Unfortunately, this report will contain almost no details on the Wharton model, according to the project director, Richard Richels. Instead, most of the MIT validation results were incorporated directly into the Wharton model. In addition to these efforts, EPRI recently implemented a policy requiring that all modeling efforts supported by EPRI funds be documented (just how fully remains to be seen).

DOE also appears to be taking significant steps in the direction of improved model validation and documentation. A March 6, 1979 list of proposed contracts from DOE's Office of Applied Analysis includes several validation projects. One of these proposals initiates a continuing relationship with the National Bureau of Standards (NBS) to develop and apply standards and procedures for the assessment and validation of energy models. Another continues a relationship with the Los Alamos Scientific Laboratory in support of the same goals. A third program provides funding

for a model validation symposium to be held in 1979 by NBS. Other proposed contracts include validation and documentation of energy demand models, oil and gas models, documentation of the Oil Market Simulation Model and of a nuclear fuel analysis modeling system, documentation of impact models, and continuation of support to MIT for developing assessment and validation procedures vis-a-vis the Coal Supply Forecasting System.

Since model validation is a comparatively new practice, almost no validation procedures have gained widespread acceptance. An NBER conference on model formulation, validation, and improvement held in 1975 identified a number of important research needs in this area. These needs include outside sample validation procedures, subsample validation procedures, sensitivity analysis, scalar measures of goodness of fit, model dynamics, analysis of residuals, disaggregation, group validation, validation experiments, model utility, tests of model consistency, and tests of model parsimony and clarity. Henize covers some of these needs in a paper presented at another workshop (see Massachusetts Institute of Technology (1975)) on the evaluation of large-scale social systems models.

Model Surveys and Evaluations

The sudden proliferation of energy models, many of them unvalidated and/or scantily documented, temporarily resulted in technology outstripping application capacity. Fortunately, a number of surveys and evaluations have recently appeared, narrowing this gap between decision makers and model builders. Several of these studies are especially relevant to energy-economy interactions. Those by Brock and Nesbitt (1977), Charles River Associates (1979), Energy Modeling Forum (1977), Griffin (1976), and

Khazzoom (1976) have already been discussed. Baughman, et al. (1978) critique the Hudson-Jorgenson, Wharton Annual Energy, and PILOT models as well as the BLS, Almon interindustry, BESOM, PIES, SRI-Gulf, and Baughman-Joskow models. Goettle, Hudson, and Lukachinski (1978) provide a detailed comparison of the Hudson-Jorgenson and DRI-PIES models. Other evaluations of a broad spectrum of energy models include Burnett and Fraley (1977), Ciliano, Limaye, and Hu (1977), Cohen and Costello (1975), Cowing and Smith (1978), Energy Modeling Forum (1978), Gordon (1976), Hartman (1978), Hausman (1975), Hieronymus (1976), M.I.T. (1975), Model Assessment Laboratory, M.I.T. (forthcoming), and Thompson, et al. (1978).

There are also numerous reviews of energy models. (To a large degree the distinction between an evaluation and a review is an arbitrary one. However, evaluations generally involve more analysis than reviews. Some studies, such as this one, provide both a review and an evaluation.) The reader interested primarily in energy-economy models can turn to Manne, Richels, and Weyant (forthcoming), National Research Council (1978), Energy Modeling Forum (1977), Charles River Associates (1979), Gilbert, Jonish, and Taylor (1979), and Brock and Nesbitt (1977). For a global view of energy modeling, the best sources are Beaujean and Charpentier (1978), Beaujean, Charpentier, and Nakicenovic (1977), and Charpentier (1975, 1976). Books by Roberts (1976), Searl (1973), and Macrakis (1974), and a book titled Energy Modelling (1974) also contain a variety of energy models as do reports by Messina (1976), M.I.T. (1975), Limaye (1974), and Pindyck (1977b).

For some background on the actual use of models (energy and otherwise), Fromm, Hamilton, and Hamilton (1975) are invaluable. Greenberger (1977),

Greenberger, Crenson, and Crissy (1976), Hoffman and Wood (1975), Karaganis (1976), Schurr (1978b), and Verleger (1974) also give some insights into the use of energy models. Goettle, Hudson, and Lukachinski (1978) present a procedure for selecting among alternative models. Kononov (1977) presents a systems approach for forecasting long-term energy development. Krohm, Mehring, and Van Kuiken (1978) study the representation of markets in optimization models. Kymn (1977), and Kymn and Page (1979a, 1979b) examine the structure of energy production in input-output models. Cole (1977) reviews several global models. Finally, Schanz (1975) explains some of the energy terminology.

CHAPTER IX

ETA-MACRO AND ETA

INTRODUCTION

Principal Developers of the Model

These models were developed by Alan S. Manne. ETA was developed when Manne was a professor of Political Economy at the John Fitzgerald Kennedy School of Government, Harvard University. Manne is currently a professor in the Department of Operations Research at Stanford University.

Type of Model and Submodels

ETA, Energy Technology Assessment, is an optimization type of model. For any given electric and nonelectric energy products, a linear programming problem is solved to achieve these products at least cost. Furthermore, the optimal levels of electric and nonelectric energy are obtained by maximizing a net benefit function. This is a nonlinear programming problem. In ETA-MACRO the benefit function is replaced by a simple neoclassical growth model. The growth path is intended to represent market behavior but it is obtained by choosing consumption to maximize a utility functional.

Complexity

These models are relatively simple optimization models. Manne (1977, p. 43) states that:

> Our specific problem contained 80 variables entering nonlinearly into the objective function. Altogether, there were 350 rows, 600 columns, and 2000 non-zero matrix elements. On the Stanford Linear Accelerator's IBM 370/168, it required 90 seconds to solve one case from a cold start, and then approximately 30 seconds for each subsequent case.

Sectors Emphasized

These models focus on the energy sector. The rest of the economy is included in ETA-MACRO but in very simple aggregate form.

Time Horizon

The models have a 75-year time horizon to the year 2050. A long time horizon makes sense in this type of model for two reasons: (1) A shorter time horizon might lead to results which are not sustainable over a longer horizon. (2) Current resource prices should reflect the increased cost of future energy sources discounted appropriately. The latter issue is implicit in these models. The choice of the time horizon is discussed in Schmitt, et al. (1977). The model is solved for sixteen discrete time points with five-year intervals.

Types of Questions Addressed

These models are designed to assess the impact of broad energy events on energy supply, demand, prices and, for ETA-MACRO, GNP and consumption. Manne (1977) focuses on the impact of a moratorium on nuclear reactor construction. Other interesting questions deal with the impact of higher coal prices, constraints on the rate of coal production, constraints on oil imports, depletion of oil and natural gas, limited uranium availability and price increases, and the timing and costs of new technologies including fast-breeder reactors and solar-electric generation (see Schmitt, et al. (1977)). ETA-MACRO has been used in conjunction with the Biomedical and Environmental Assessment Division (BEAD) at Brookhaven to estimate health and environmental costs of energy production and use (Hamilton and Manne (1977)). Also ETA-MACRO can be used as part of a cost-benefit analysis of

R&D expenditures on new energy technologies. Manne and Richels (forthcoming) analyze the U.S. breeder reactor program. Different possible events are taken into account using probabilistic decision trees.

These models estimate overall consequences of broad energy sector events. According to Manne (1977, p. 5):

> More details would be needed to analyze specific proposals for energy conservation or specific projects for the expansion of capacity within the electricity, petroleum and gas industries. It is impractical, however, to construct a single model to answer all questions related to energy policy. Instead, it appears more reliable to depend upon informal information flows back and forth between individual analyses--each designed to handle specific issues at an appropriate level of detail with respect to time, space and physical product description.

ENERGY-ECONOMY INTERACTIONS

In ETA the energy sector is not linked to other macroeconomic aggregate variables. Therefore, in this section we refer only to ETA-MACRO. In ETA-MACRO electric and nonelectric energy are factors of production, i.e., intermediate goods. Hence they directly affect gross output. The cost of producing energy (with investment in the energy sector treated as a levelized capital charge) is subtracted from gross output to get GNP. The prices of electric and nonelectric energy affect other factor prices (the return to capital and the wage rate) and ultimately they affect capital accumulation and growth. Figure 9-1 gives an overview of ETA-MACRO.

STRUCTURE OF THE ENERGY SECTOR

Different versions and computer runs of these models have incorporated slightly different formulations of the energy sector. The list of energy technologies shown in Table 9-1 was used by Manne (1977) to analyze the effects of a nuclear moratorium.

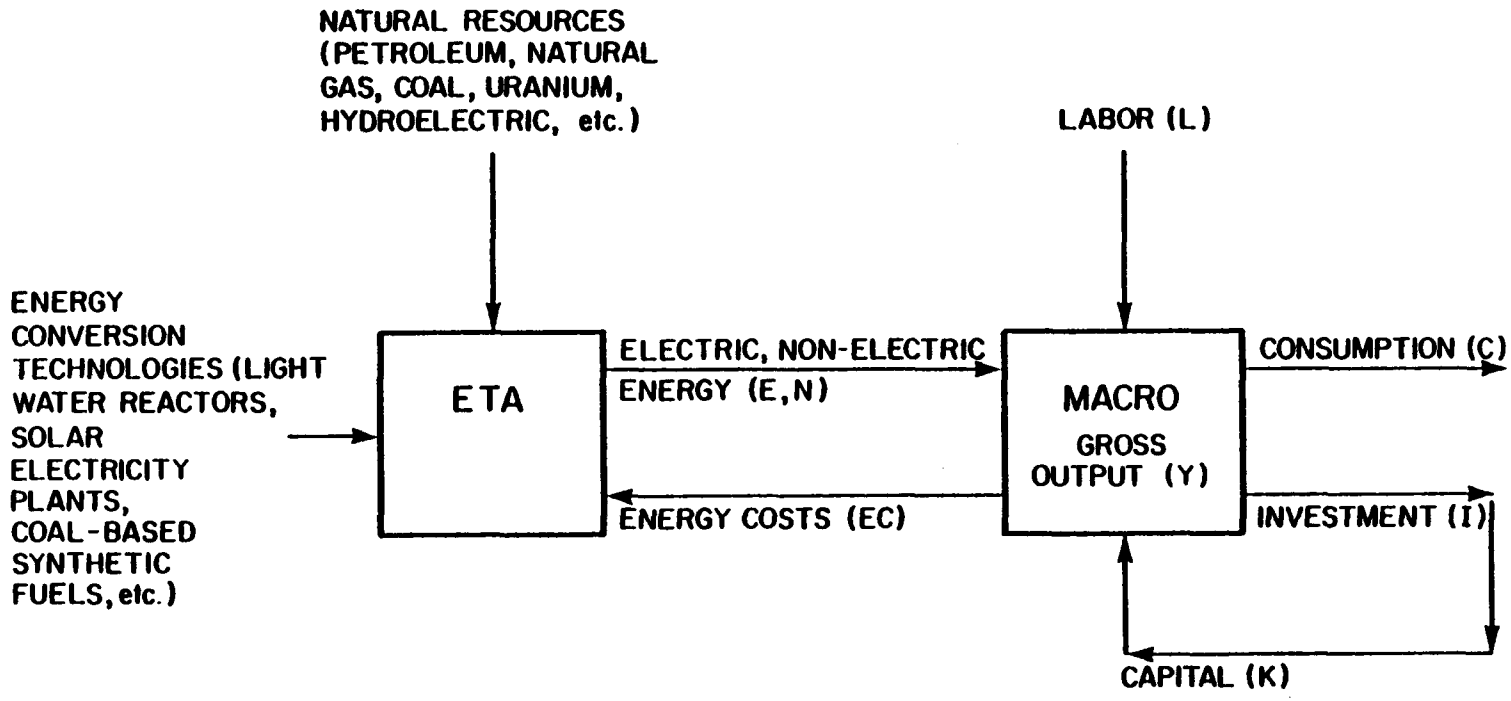


Figure 9-1. An Overview of ETA-MACRO

TABLE 9-1

IDENTIFICATION OF TECHNOLOGIES

Technology Number	Name	Identification
Electric		
01	HYDR	Hydroelectric, geothermal, wind, etc.*
02	RFOS	Remaining initial fossil electric*
03	COLL	Coal-fired electric, low-cost regions
04	COLH	Coal-fired electric, high-cost regions
05	LWRA	LWR, no plutonium recycle, .2% tails
06	LWRB	Same as LWRA, but applies to cases involving no new nuclear reactors
07	LWRC	LWR, plutonium recycle, .2% tails
08	FBRX	Liquid metal fast breeder reactor, early oxide
09	ADVX	Advanced solar electric or fusion
Nonelectric		
10	PETG	Petroleum and natural gas
11	SYNF	Coal-based synfuels (liquids and gases)
12	SHAL	Shale oil
13	ELHY	Electrolytic hydrogen
14	NAE5	Nonelectric alternative energy systems--equivalent to oil and gas at $5/million BTU
15	NAE8	Same as NAE5, but applies to cases involving costs of $8/million BTU
16	CLDU	Coal--direct uses other than electricity and synfuels*

*Exogenously determined activity levels.

Source: Manne (1977, p. 17).

Energy Resources and Extraction Costs

The model includes stocks of petroleum, natural gas, coal and uranium with separate stocks for each extraction cost grade. Extraction costs are constant parameters which are entered for each resource grade.

Crude oil production depends on current and past investment reflecting a decline curve in oil production. Constraints are placed on the rate of coal production.

Energy Conversion and Distribution, Capital Requirements, and Costs

Energy conversion technologies are shown in Table 9-1. Little emphasis is given to energy transmission and regional cost differentials. Only coal-fired electricity generation is divided between low-cost and high-cost regions. Energy conversion costs are specified for each technology. Both current and capital costs are given. However, capital costs are treated as a levelized capital charge assuming a constant discount rate for the firm (13% real discount rate in Manne (1977)). Capacity expansion is modeled for each technology. An energy plant has a life of thirty years.

In Manne (1977) cost parameters are taken from the CONAES Modeling Research Group. Two other sets of cost parameters are reported in Manne (1976) and Schmitt, et al. (1977).

Energy Products and Prices

There are two broad energy products: electric and nonelectric energy. Each of these types of energy can be produced using many different technologies as indicated in Table 9-1. Prices of these two energy products are determined implicitly from the optimization solution. Since there are no energy taxes or other distortions and since factors of production adjust

immediately to their long-run values given current factor prices, the prices of the energy products must be their value marginal products, which can be easily computed from the aggregate production function. On the supply side each of these prices must be equal to total long-run marginal cost of producing an additional unit of the respective energy product. This marginal cost concept is determined from the optimization problem and takes into account current costs and capital charges plus shadow prices reflecting binding constraints. These constraints could be a stock constraint on resource availability (e.g., limited stock of oil) or a flow constraint (e.g., maximum rate of coal production). Thus the cost of using an additional unit of energy today exceeds the extraction cost because depletion of resource stocks implies that higher-cost energy substitutes must be used sooner. These shadow prices are discussed and computed by Nordhaus (1973).

Interfuel Substitution

There is considerable flexibility in interfuel substitution. However, no adjustment costs are modeled. (Of course, capacity must be accumulated in alternative sources.) The combination of energy sources and the mix of electric and nonelectric energy are determined optimally from the maximization procedure.

STRUCTURE OF THE U.S. ECONOMY

This section refers only to ETA-MACRO. As was discussed in the last section, the energy sector is disaggregated. However, the rest of the economy is aggregated into a single sector. This sector produces final demand goods which can be used for consumption, investment, or the production of energy. Gross output from the nonenergy sector is given by an

aggregate production function:

$$Y = [a(K^{\alpha}L^{1-\alpha})^{\rho} + b(E^{\beta}N^{1-\beta})^{\rho}]^{1/\rho}$$

$$\rho = (\sigma - 1)/\sigma \qquad (9.1)$$

where K, L, E, and N are capital, labor in efficiency units, electric energy and nonelectric energy, respectively. Manne (1977, pp. 5-7) states that some properties of this production function are the following:

- There are constant returns to scale in terms of these four inputs.
- There is a <u>unit</u> elasticity of substitution between one pair of inputs--capital and labor--with α being the optimal value share of capital within this pair.
- There is a <u>unit</u> elasticity of substitution between the other pair of inputs--electric and nonelectric energy--with β being the optimal value share of electricity within this pair.
- There is a <u>constant</u> elasticity of substitution between these two pairs of inputs--the constant being denoted by σ.

The parameters a, b, α, and β are chosen (but not estimated in a statistical sense) to be consistent with 1970 data, a time at which the economy is assumed to be in long-run equilibrium. (Clearly after the 1973 oil price increase the economy was not in long-run equilibrium regarding energy usage.) The procedure is briefly discussed in Manne (1977). It was assumed that the elasticity of substitution σ is in the range of 0.1-0.4. A value of 0.25 was chosen for σ for the base case with other computer runs testing the sensitivity to changes in σ.

Actually the above production function gives output from new capital only. New capital (installed in 1975 or after) remains like "putty" forever and can be used with the energy aggregate in varying proportions. Output from old capital declines exponentially over time due to depreciation. Old

capital is like "hard baked clay." It must be used in fixed proportions with energy and labor. Total output is the sum of the outputs using old and new capital.

MACROECONOMIC STRUCTURE

Output is determined on the supply side as in neoclassical growth models. It is divided as follows:

$$Y = C + I + EC \tag{9.2}$$

where EC is energy cost. There are no government or international sectors. Once Y and EC are determined, the only remaining question is how to divide GNP = Y - EC between consumption (C) and investment (I). The consumption/saving decision at each time period is based upon the maximization of the following utility function:

$$\sum_{t=0,5}^{70} \left(\frac{1}{1+\delta}\right)^{t} \log C(t) + \Phi(C(75)) \tag{9.3}$$

where δ is the utility discount rate reflecting time preference and Φ is the total utility following the terminal time which depends on the terminal level of consumption. This utility function will be discussed again in the evaluation section.

Other macroeconomic variables like inflation, capacity utilization, unemployment, money and other financial assets, wealth and the nominal interest rate are not included in the model. Hence the model is not intended to deal with stabilization questions.

GROWTH AND TECHNICAL CHANGE

Technical change is assumed to be labor augmenting, i.e., Harrod-neutral technical progress. Hence it is convenient to express labor input in efficiency units which increases both because of labor-force growth and technical progress. Manne does not separate these two components. Instead he specifies the growth in labor efficiency units directly (see Manne (1977, p. 10) for the assumed growth rates).

Growth depends heavily on capital accumulation. The change in capital depends on depreciation and current and previous period investment.

MODEL EVALUATION

Lester Lave (1977b, p. 280) sums up ETA-MACRO nicely: "While small and comparatively simple, it is nonetheless an elegant model capable of giving many insights." We agree entirely with this assessment. However, as with all energy models, there are many issues which remain unsolved. Because ETA-MACRO is simple and has a clear conceptual basis, it is particularly attractive to use as an example in discussing some of these unsolved issues. A discussion of these unfinished matters seems more useful than a discussion of what has already been accomplished. Also the discussion will focus on the macroeconomic aspects of the model rather than on the energy sector.

Short-Run Considerations

ETA-MACRO is a long-run model with output determined on the supply side. Hence many cycles, shocks and adjustment processes are suppressed. Presumably, the long-run path should represent the average behavior of the economy. However, whether actual growth is close to potential growth depends

on whether or not macroeconomic stabilization problems can be mitigated. Despite its importance, this topic will not be addressed here. However, there is one macroeconomic aspect of ETA-MACRO which should be mentioned. Manne treats investment in the energy sector on a levelized capital charge basis, as if capital were rented. This approach is probably satisfactory if actual investment is not overly concentrated in a few time periods. In such a case interest rates would be bid up, nonenergy investment would be crowded out, and the energy-related construction sectors would be operating above capacity. This would drive up prices of energy facilities and desired investment in these facilities could exceed actual investment.

In order to understand the importance of Manne's assumption about levelized capital charges, imagine the following scenario. Existing energy technologies based on coal or nuclear power have undesirable externalities. Energy plants based on oil and gas have long-term fuel supply uncertainties. New technologies are unproven and will probably improve in cost and reliability with experience. Hence, energy investment might be postponed until an energy crunch is imminent. At that time there could be some serious capital market effects. This possibility is assumed away in the Manne model.

The Production Function and the Elasticity of Substitution

For new capital installed in 1975 or thereafter the production function is given by equation (9.1), with an elasticity of substitution of σ. However, in the earlier periods of the model the actual elasticity of substitution is much less than σ. The reason is that old capital uses a fixed proportion of energy. In the early periods of the model old capital

dominates the substitution picture. Hence the model is probably not suited for 5, 10 or 15 year estimates of the economic impact of energy price rises. In the long run, say after thirty years, new capital dominates and the actual elasticity of substitution approaches σ. If medium-run economic impacts are of interest, a better approach would be to give each vintage of capital a putty-clay property with a small short-run elasticity of substitution for previously installed capital as in Gunning, et al. (1976). Of course, this approach adds considerable complexity to the model. However, without more of this detail ETA-MACRO must be considered a strictly long-run policy tool.

Capital

In this model a rising energy price does not lead to underutilization of marginal capital and accelerated obsolescence of energy intensive capital. The reason is that capital is homogeneous and new capital is malleable. The underutilization problem and its impact on growth was discussed in Chapter III.

Growth, Composition of Output, Productivity and Technical Progress

The sources of growth in this model are capital accumulation and growth of effective labor. The latter is the growth of the labor force plus the growth of Harrod-neutral technical progress. Of course, it is convenient to model technical progress as purely labor augmenting. Furthermore, as real wages have risen there has been an incentive to focus R&D on labor-saving innovations.

However, as energy prices rise one would expect energy-saving innovations to become more important. Hence, energy-augmenting technical progress

may be important. Presumably this energy savings is lumped in with the notion of substitution of capital and labor for energy. Although an increase in energy-augmented technical progress and an increase in the elasticity of substitution have some similar consequences, the intertemporal effects are quite different.

Growth rates for population and productivity are projected for the most part by extrapolating trends. However, over a seventy-five-year period it is hard to forecast changes in these trends. Hence, there should be considerable uncertainty associated with the growth rate of effective labor data. Since the solution is very sensitive to these data, energy policy should be evaluated using a set of different scenarios which reflect this uncertainty.

Another issue related to growth is the sectoral composition of output. As energy prices rise, demand may shift to sectors which are less energy intensive. However, these sectors typically have slower growth in productivity which in turn affects average productivity and output growth. This issue was discussed in Chapter II. These effects are not explicitly accounted for in the ETA-MACRO model because this model has only one nonenergy sector.

The Consumption-Savings Choice and the Welfare Functions

GNP growth depends heavily on capital accumulation and hence on the consumption-savings choice. Manne assumes that at each point in time consumption is chosen to maximize the intertemporal utility function (equation (9.3)). Manne states that since this process represents consumer behavior, he has constructed a descriptive or positive model rather than a welfare-oriented or normative model. However, it seems useful to pursue both approaches.

Consider a descriptive model of consumer behavior. Presumably individuals making their consumption-saving choice do not maximize the utility of aggregate consumption but rather their own consumption. This implies that per capita consumption would be more appropriate than aggregate consumption in the utility function. These two variables differ because the labor force is changing. The choice is not trivial. It substantially affects the growth path, particularly in later years. The other observation regarding the descriptive model is perhaps more serious. An individual will choose a consumption path to equate the consumption discount rate obtained from his utility function in equation (9.3) with the rate at which he can transform current savings into future consumption. The latter is the after-tax rate of return on investment. However, in ETA-MACRO, Manne sets the consumption rate of discount, i.e., the time rate of change of the consumption discount factor (see Arrow and Kurz (1970, pp. 59-60)), equal to the before-tax rate of return to capital. Since the before-tax rate is much higher, he has to somehow get a high consumption rate of discount. He does this by picking quite high values for the rate at which consumers discount utility δ, i.e., δ falls in the range of 8-12%. Hence his consumers have a very high rate of time preference.

Now consider a normative model where the utility function (9.3) is interpreted as a social welfare function. The social goal is to pick a consumption path which maximizes the social welfare function. Here the social consumption discount rate should equal the before-tax rate of return, which is what Manne has done. Also it makes more sense to have the utility function depend on aggregate consumption in this case. However, perhaps a better form of welfare function (preferred by Arrow and Kurz (1970)) is

to make utility depend on per capita consumption (since there may be diminishing marginal utility in per capita consumption) but to weight the utility by the population size.

Finally, in the normative case where Manne is determining what society should do rather than what it will do, the utility discount rate δ should be much lower. Some economists argue that δ equal to zero is appropriate since it is unfair to value the consumption of the next generation less than that of the current generation. Other economists argue δ equal to one or two percent is appropriate to account for uncertainty about the future. A δ of ten percent is clearly unfair. A lower δ would imply more investment, a larger equilibrium capital/labor ratio, a lower rate of return to capital, and higher per capita consumption.

In equilibrium the consumption per effective unit of labor is constant which implies real per capita consumption is increasing at the rate of Harrod-neutral technical progress. However, a lower δ implies that constant consumption per effective unit of labor is higher. These results come from the standard optimal growth literature (see Arrow and Kurz (1970, Chapter 3)).

Manne's model differs from the standard growth model in three ways which do not affect the growth path much or the equilibrium at all. These differences are the following: (1) a discrete time formulation; (2) capital accumulation depending on both current and lagged investment; and (3) subtracting out energy costs from gross output. One should think of gross output less energy costs as net output or value added in the standard neoclassical growth formulation.

The last point involves the generality of the welfare function. Manne has assumed that the elasticity of marginal utility with respect to

consumption is 1.0 (see Arrow and Kurz (1970, pp. 59-60) for an interpretation of this elasticity). This result follows from the logarithmic utility function. However, the concept of diminishing marginal utility can be expressed more generally in the form

$$u(c) = \frac{1}{1-\varepsilon} C^{1-\varepsilon} \qquad \varepsilon \neq 1$$

$$= \log C \qquad \varepsilon = 1$$

where ε is the elasticity of marginal utility reflecting the concavity of the utility function. Then the consumption rate of discount is

$$r_c = \varepsilon \frac{\Delta c}{c} + \delta.$$

This r_c is equated to the rate of return. Hence it should be clear that the preference parameter ε, reflecting the extent of diminishing returns in consumption, is important in determining the utility maximizing consumption path. Heuristically, the larger is ε, the more the consumption path is smoothed out. A large ε avoids the problem of an excessive initial savings ratio. However, a large ε reduces the equilibrium capital/labor ratio and hence per capita consumption. Although Manne sets $\varepsilon = 1$ for convenience, the model user should be aware that the results are probably sensitive to this specification of preferences.

Another aspect of the consumption-saving choice is that if this in fact is a choice problem then the initial consumption C(0) should also be chosen. However, Manne fixes this initial condition, presumably at its historical value.

For the descriptive approach the justification for this is probably that individuals have been maximizing their utility all along and hence C(0)

is already optimal. This justification also requires that consumers previously had as much information about the future, particularly energy availability and cost. A second justification involves adjustment costs in changing the current level of consumption. However, if such costs exist they should be modeled explicitly and then the optimal C(0) could be chosen.

For the normative case where welfare is maximized, there is no justification for fixing C(0). Fixing C(0) as a constraint and thereafter equating the consumption rate of discount to the rate of return is not a correct procedure for computing optimal paths. It is not even a second best procedure for maximizing welfare subject to a constraint.

Although the corrections to the technical problems mentioned here can be easily incorporated into the model, the approach to determining consumption by solving a seventy-five-year intertemporal maximization problem should be considered. This approach frequently leads to very large variations in the savings ratio over time. Typically, the savings ratio starts off high and gets small as the equilibrium capital/labor ratio is approached. Sometimes this approach also leads to counter intuitive results. For example, in the Manne (1977) results, the savings ratio actually increases initially as the utility discount rate δ is increased! This result follows from equating r_c to the rate of return, but one wonders if an economy would really behave in that way.

It seems that with this approach parameters like δ must be picked not entirely on the basis of the evidence but on the basis of which values give reasonable results. Hence, there are some ad hoc procedures involved even with the intertemporal maximization problem.

We would like to suggest that more realistic forecasts (and perhaps more transparent) could be obtained by less sophisticated procedures for determining consumption. One need not use a simple Keynesian consumption function. Some wealth effects and intertemporal considerations could be built into the model.

Discounting, Distortions and Resource Shadow Prices

The ETA-MACRO model has four discount rates: The firms' discount rate for computing capital rentals, the marginal product of capital, the consumption rate of interest, and the social discount rate for public projects. All of these rates should be equated in an ideal economy. Instead, Manne decides to do the following: Set the firms' real discount rate at 13%. This rate is used to compute the levelized capital charge in determining energy costs. If one thinks that 13% is high, then energy costs are biased upward in this model. The firms' discount rate is probably not set equal to the marginal product of capital for convenience. The latter starts off at approximately 13% and does not change too much throughout the simulation. However, if the marginal product of capital did significantly shift during a simulation, it would seem more appropriate to shift the firms' discount rate as well. If this were done, the solution to the two submodels--growth and the energy sector--would involve a complicated simultaneous equation.

As was discussed in the last section the consumption discount rate is set equal to the marginal product of capital. (Recall that for a descriptive model it should be set equal to the after-tax return to capital.)

Finally, Manne considers the possibility that the social discount rate is considerably less than the private discount rate. The usual argument

for this is that taxes create a wedge between the marginal product of capital and the consumption discount rate. The social discount rate then is somewhere between these two rates. However, in ETA-MACRO the consumption rate of discount is equal to the marginal product of capital so that is not a reason for the public discount rate to be less than these private rates. It seems that the reason these rates are so high is that consumers are assumed to have a very high rate of time preference, δ.

The value of the social discount rate is by no means a trivial question. The vigor with which society today prepares for the possible energy crunch in the early 21st century depends heavily on this social discount rate. Also the present social value of resource stocks (scarcity rent) depends heavily on this rate (see Hanson (1977)). Hence the social discount rate heavily affects the rate at which energy resources should be depleted. We think that a much lower social discount rate is appropriate than the value of the consumption rate of discount (about 13%) which Manne used in his model.

As Lave (1977b) points out, ETA-MACRO assumes that full incentives exist for energy conservation and developing new energy technologies. In fact price regulations, uncertainty regarding government policy and future energy prices, and tax distortions affecting the rate of return are all likely to impede the transition to a less energy-intensive society with a new mix of energy sources. It would be useful to model the effects, and hence the costs, of these regulations and distortions on the economy.

CHAPTER X

DRI LONG-TERM INTERINDUSTRY TRANSACTIONS MODEL (LITM) (THE HUDSON-JORGENSON MODEL)

INTRODUCTION

Principal Developers of the Model

The original funding for the Hudson-Jorgenson model came from the Ford Foundation Energy Policy Project, although other sources of funding provided for continued development of the model. For a history of the early contractual agreements, see Mead (1976).

The first description of this model appeared in the Bell Journal of Economics (Hudson and Jorgenson (1974)). DRI has further developed and refined the original version which is now called LITM. Descriptions of the new version are contained in Hudson and Jorgenson (1978c) and Dullien (1976). The original interindustry model had nine sectors; the new version has ten sectors; the change involved separating natural gas into two sectors.

DRI is currently expanding LITM to 36 sectors, but detailed descriptions of this model are not yet available. With this many sectors, the number of parameters which must be estimated econometrically to determine input-output coefficients becomes unmanageable. Hence, a multilevel approach is needed where sectors are aggregated at different levels and appropriate separability assumptions are made.

Type of Model and Submodels

LITM is a system for integrating two econometric submodels. One is a macroeconomic model of aggregate economic growth. The other is an interindustry model with price sensitive input-output coefficients. These two

econometric submodels can also be linked to energy supply models which will be discussed below. Figure 10-1 provides an overview of the economic flows within the model.

Complexity

The submodels are not extremely complex. The macroeconomic model is a fairly standard neoclassical growth model with some additional features like a government sector, financial wealth, and a labor-leisure choice. The interindustry model has ten sectors. To compute the input-output coefficients a set of twenty-seven simultaneous equations must be solved numerically. Presumably this presents no computational burdens.

Sectors Emphasized

The primary emphasis in LITM is on the energy sector. There are three primary energy sectors (oil, gas, and coal) and three energy conversion sectors in the interindustry model. However, the supply side of the primary energy sectors is not developed in detail. Hence, energy supply models have been linked to LITM as will be discussed below.

However, even though the focus of the LITM model is on the energy sector, the nonenergy sector is at least detailed enough to trace out the effects of different sectoral growth rates (in the four nonenergy sectors) and the macro-model is detailed enough to be consistent with the National Income and Product Accounts.

Time Horizon

LITM is a medium-run model giving economic projections up to the year 2000.

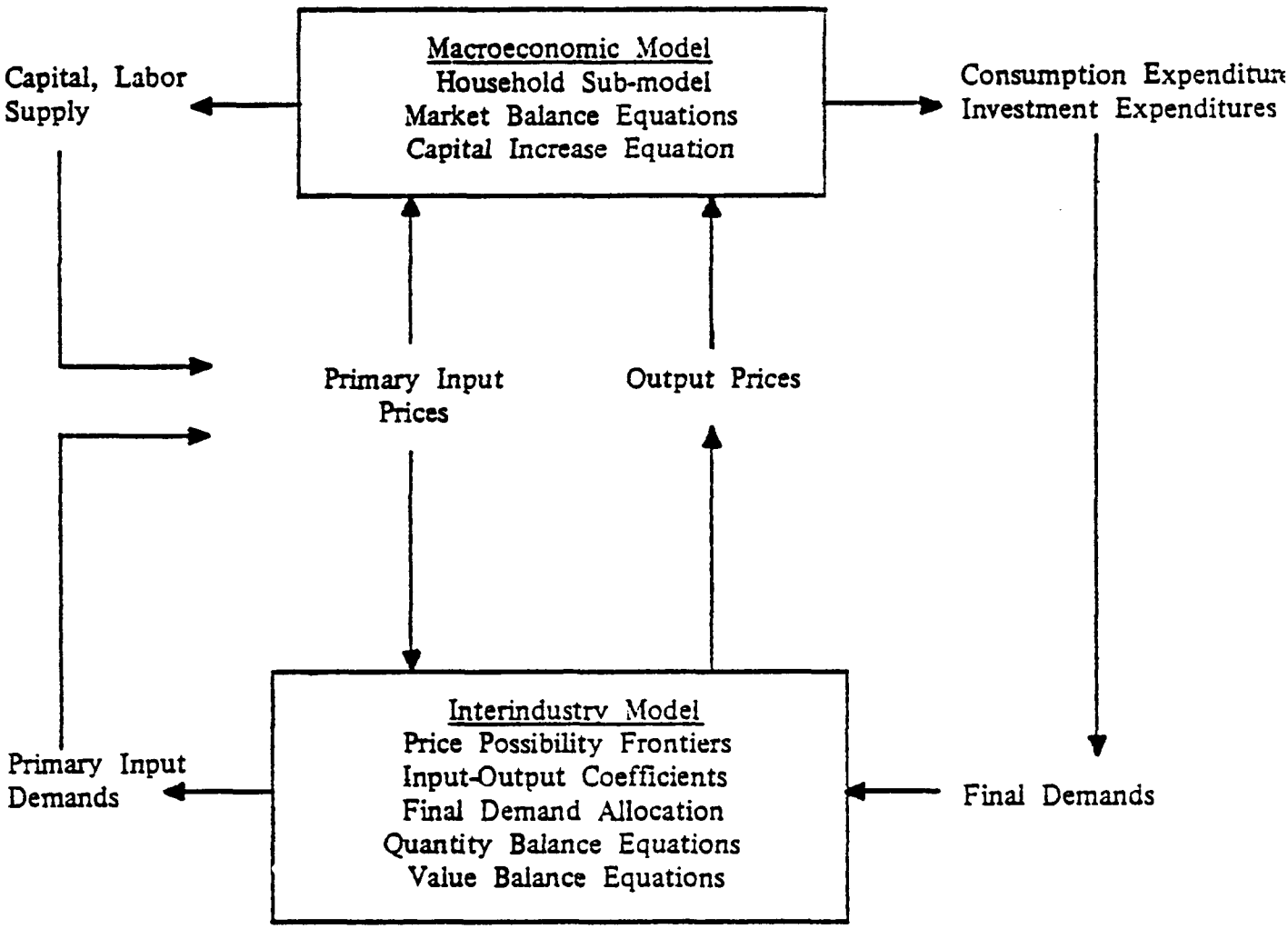


Figure 10-1. Overview of Economic Flows in the Integrated Model

Types of Questions Addressed

This model has been used to address three types of questions: energy-economy projections, the effects of policy levers on energy and economic growth, and the impact of higher energy prices on the economy. The LITM system has also been used with the Brookhaven system for analyzing the economic impacts of specific and detailed energy policies.

Recently completed projections using this model are contained in Hudson and Jorgenson (1978c). Key variables in the projections are energy quantities by type for both primary and delivered energy, energy prices, oil imports, GNP growth, relative growth rates of sectors, and factor prices.

The model has been used to analyze the effects of several policy levers on energy and economic growth. For example, the effects of different world petroleum prices and the effects of a BTU tax were analyzed in Hudson and Jorgenson (1974). It has also been used to compare different policies to achieve oil independence. The policies considered were a BTU tax, an energy sales tax, and a tax on petroleum alone (Chapter 2 in Jorgenson (1976)). The model has been used to construct alternative scenarios for different energy conservation programs. The first such use was with the Ford Foundation Energy Policy Project (Freeman (1974), particularly Appendix F). More recent analyses of energy conservation policies are contained in Hudson and Jorgenson (1978a and 1978c). The four policies considered are the following:

> Policy 1: Taxes are imposed on U.S. petroleum production to bring domestic petroleum prices to world levels; natural gas prices are increased but price controls are retained; energy conservation is stimulated by taxes on use of oil and gas in industry, restriction of oil and gas use by electric utilities,

subsidies for insulation of structures, and mandatory performance standards for energy-using appliances.

Policy 2: The measures included in Policy 1 are combined with tariffs on imported oil rising to $4.50/bbl in 1985 and to $7.00/bbl in 2000, and with corresponding taxes on natural gas.

Policy 3: Policy 2 is combined with excise taxes on delivered energy sufficient to reduce total primary energy input in 2000 to 90 quadrillion BTU.

Policy 4: Policy 3 is combined with excise taxes on delivered energy sufficient to reduce total primary input in 2000 to 70 quadrillion BTU.

Jorgenson analyzes President Carter's specific energy policies in his paper (1978). The Hudson-Jorgenson model has also been used by Cogan, Johnson and Ward (1976) to analyze the impacts of various policies on employment. The policies they look at include decontrol of oil prices, oil import quotas, and a tax on crude oil.

Finally, the model has been used to look at the historical effects of the 1973 increase in world oil prices (Hudson and Jorgenson (1978a)). The recovery from the 1974-75 recession has been characterized by a slower than normal increase in the rate of return, a slower than normal increase in investment spending, and a slower than normal increase in the growth of labor productivity. "Normal" here refers to comparisons with previous recoveries since World War II. Hudson and Jorgenson base their interpretation of these events on the assumption that capital and energy are complements. The high growth rate of employment is explained by the hypothesis that energy and labor are substitutes. Hence, Hudson-Jorgenson claim that higher energy prices have had a substantial impact on the U.S. economy, not only in terms of the severity of the 1974-75 recession, but also in terms of the rate of economic growth following the recession. In another paper,

Hudson and Jorgenson (1978b) compare the actual GNP in 1976 with what it would have been had energy prices continued at their 1972 levels. Again they report significant impacts of higher energy prices. The higher energy price has reduced energy consumption in three ways: by reducing the level of GNP; by changing the mix of goods produced in favor of less energy intensive goods; and by substituting capital and labor for energy in producing the mix of goods.

These numerical results should be interpreted with care. As soon as the oil price changes, the model immediately predicts long-run impacts. That is, factor substitution, substitution between consumption goods, and the level of GNP all immediately adjust to their long-run values. One wonders whether the three-year period from 1973 to 1976 was long enough for these adjustments to approach long-run equilibrium.

In order to analyze the economic impact of conservation policies affecting specific industries, products or technologies, or to analyze the economic impact of energy supply policies of a detailed nature, the LITM model has been linked to other energy supply models. The link to the Brookhaven energy model BESOM is described in Hoffman and Jorgenson (1977). The LITM model was used with the Brookhaven model DESOM to analyze the effects on economic growth of a moratorium on additional nuclear power plants (Behling, et al. (1977)). The policies described in Hudson and Jorgenson (1978a) were analyzed using LITM with the Brookhaven TESOM model. The LITM system is also capable of being linked to the Baughman-Joskow Regionalized Electricity Model, the MacAvoy-Pindyck model of natural gas supply (Bernanke and Jorgenson (1975)), the NPC-Stilt oil and natural gas supply model and the Zimmerman coal model.

ENERGY-ECONOMY INTERACTIONS

Direct Interactions

The key energy related variables and policy levers are the price of oil and various tax policies such as an energy sales tax, petroleum tax or BTU tax. These specific energy variables affect the price of the energy aggregate. This price affects the substitution between capital, labor, energy, and materials for each of the ten sectors. Thus the energy price affects factor shares, input-output coefficients, and prices of the sectoral outputs.

Indirect Interactions

Once the input-output coefficients are determined, all the direct and indirect impacts of a change in an energy-related variable on sectoral output can be traced through. In addition the total demand for capital, labor, and imports is determined. (Among the most important questions addressed are the impacts of reduced energy consumption on the demand for capital and employment. The former is important because it affects investment and economic growth.) Other macroeconomic impacts are the level and composition of consumption, the labor supply choice, and the rate of return to capital.

STRUCTURE OF THE ENERGY SECTOR

Of the ten producing sectors, six are energy related. Three deal with the extraction of natural resources and three deal with the conversion and transportation of primary resources into delivered products.

Energy Resources

Three energy resources are considered: coal, oil and natural gas. The extraction process for these resources is described in the same form as the producing sectors, i.e., with price possibility frontiers. For example, in order to extract a ton of coal, capital, labor services, and outputs from the other producing sectors are needed. Hence, price sensitive input-output coefficients can be constructed for coal production. The depletion of the stocks of high-grade natural resources is not taken into account. However, a price can apparently be set on the natural resource depleted, with this price passed on in terms of higher prices of delivered energy products. Certainly the model is capable of assigning an exogenous price to crude oil. Furthermore, the prices of energy resources can be increased with taxes. In addition, the model not only captures domestic extraction but also oil imports. The simple input-output model of natural resource extraction is quite crude. Therefore, the LITM system has been linked with several energy supply models.

Energy Conversion and Distribution

Energy conversion and distribution are handled like any other producing sector. Of course, among the inputs purchased are the outputs of primary energy sectors. The three conversion sectors are petroleum refining, electric utilities, and natural gas utilities.

Prices of Energy Products

Prices of energy products are determined as part of the solution in the set of ten sector prices. These prices represent long-run marginal costs including capital rental and the costs of primary energy.

Interfuel Substitution

Interfuel substitution takes place in this model due to the price sensitive input-output coefficients. For example, if the price of oil rises relative to coal, electric utilities will substitute coal for oil, i.e., the input-output coefficients shift.

STRUCTURE OF THE U.S. ECONOMY

Level of Aggregation

The structure of the U.S. economy is described by the ten-sector inter-industry model. The four nonenergy sectors are the following:

1. Agriculture, non-fuel mining, and construction
2. Manufacturing excluding petroleum refining
3. Transportation
4. Communications, trade, and services.

This breakdown of the nonenergy sector, although still very aggregated, captures some important issues regarding energy-economy interactions. Manufacturing and transportation are capital intensive and energy intensive. Services are labor intensive and not energy intensive. Hence, a major impact of higher energy prices is a shift in the composition of output away from energy intensive sectors. H-J report that in manufacturing, energy and capital are complements. As a result, a reduction of energy also reduces capital demand, and through an increased level of services increases labor demand.

Factors of Production

The factors of production are capital, labor, a group of inputs called energy, and a group of inputs called materials. Separability assumptions

are needed to define these two groups. Capital and labor are both homogeneous. There is no specialized capital or vintage. The energy factor is an aggregation of the energy sectors and the material factor is an aggregation of the nonenergy sectors.

Substitution Possibilities

The substitution possibilities between capital, labor, energy and materials (as well as interfuel substitution within the energy aggregate and intersectoral substitution within the materials aggregate) are obtained from the structure of production for each sector. Assumptions regarding the form of the production function and regarding competitive market structure are used to derive a translog price possibility frontier. Allen partial elasticities of substitution and price elasticities of factor demands are derived from the estimated parameters.

MACROECONOMIC STRUCTURE

Consumption and Investment

Consumption is determined from a consumption function involving wealth and current income (including the imputed value of leisure time). There is a production possibility frontier specifying attainable levels of output of investment goods and consumption goods. Once consumption is determined from the consumption function, investment follows from the production possibility frontier. It should be noted that LITM has two modes of interaction. In the mode where the macroeconomic growth model dominates, an aggregate production possibility frontier is specified and estimated. In the other mode the production possibilities are obtained by aggregating the sectoral outputs from the interindustry transactions model.

Consumption is allocated among sectors on the basis of consumer optimization using a translog utility function approach. The allocation of investment among sectors is exogenous.

Government Sector

Government spending is divided into consumption and investment goods. Government purchases of consumption and investment goods are both exogenous, as is government production of services.

International Sector

The international sector plays a minor role. Imports are included as an input to the interindustry transactions model. In the wealth equation, foreign bonds are included. However, questions relating to trade deficits and the balance-of-payments are not dealt with in the model.

Inflation, Capacity Utilization, and Unemployment

Since this is a long-run equilibrium model, there is no place for unemployment or underutilization of capacity. An exogenous unemployment number can be inserted. The rate of inflation is also exogenous. This rate is obtained by picking the path for the rental price of capital (PKD) exogenously. Inflation figures are often reported but these seem to be based on estimates outside the model. This point is not adequately brought out in the publications, leaving the reader with the impression that inflation was somehow carefully modeled. However, this does not seem to be the case.

Asset Markets, Wealth, and the Interest Rate

There is only one endogenous asset--physical capital. A wealth measure is given involving capital and foreign and domestic bonds. However, bonds

are exogenous. Money plays no role in the model, since the model is long run in nature. The interest rate is determined as a nominal after-tax rate of return to capital, including capital rental and capital gains.

GROWTH AND TECHNICAL CHANGE

Population growth is exogenous. Technical change leading to productivity increases is exogenous in the sectors of the interindustry transactions model. However, as Jorgenson himself points out, one fears that if energy consumption and investment are reduced in a sector, the growth of productivity will be reduced also. For example, in manufacturing, the high historical growth rates for productivity may not be sustainable when energy consumption is reduced. Also productivity is a key variable affecting growth and future GNP. Hence, if an energy reduction adversely affects productivity, the cost of that energy reduction may be much greater than the H-J model predicts.

The capital stock grows as net investment is accumulated. As factors are substituted in the interindustry transactions model, there are no adjustment costs.

EVALUATION

It should always be kept in mind that this is a long-run model. Full long-run adjustments take place immediately after an energy variable is changed. Capital is homogeneous and malleable. No adjustment costs are included in the model. Although Hudson and Jorgenson readily admit the long-run nature of the model, they do not restrict its use to long-run questions. For example, short-run adjustment behavior is analyzed in

papers by Hudson and Jorgenson (1978b) and Jorgenson (1978). These short-run questions are probably not appropriate applications of the LITM model.

The H-J model was extensively evaluated in a January, 1976 workshop sponsored by the Electric Power Research Institute (Khazzoom, 1976). Some of the following points were raised at this workshop:

- The price possibility frontiers are estimated with data constructed from only three input-output models of the U.S. Additional data are obtained by interpolation with some adjustments. Since there are a large number of parameters to be estimated, one cannot have much faith in the estimates. Hence, all the resulting elasticities are suspect (Khazzoom, Supplement to Chapter 2).

- H-J assume reversibility. That is, they assume that the production possibility frontier the economy moved along (substituting capital for energy) when energy prices were low, is still applicable for conserving energy now that energy prices are high (Khazzoom, Chapter 2).

- Productivity is likely to fall as energy is reduced, a problem ignored by Hudson and Jorgenson.

- The dynamics of the adjustment process are left out of the model. Is there a feasible short-run path to the long-run equilibrium that the model describes? The importance of and problems with the short-run transition path are discussed by Russell (Khazzoom, Chapter 7) and Adams (Khazzoom, Chapter 12).

- The assumption of perfect competition may not be a good approximation in all cases, especially with extensive government regulation.

- Historical data used to estimate the translog price possibility frontiers may not be consistent with long-run equilibrium (Khazzoom, Chapter 16).

- The flexible form of the translog price possibility frontier allows a second order approximation to any smooth production function. This is a very desirable property provided one is only interested in small changes from the region in which the function was estimated. However, looking at impacts of energy prices on long-run economic growth involves large changes in prices and factor proportions. Since the translog

function only gives a local approximation, there is no guarantee that it represents the actual production function for large changes in prices. In fact, the partial elasticities of substitution and the price elasticities of factor demands are very sensitive to where one is on the price possibility frontier. Input-output coefficients, if not restricted, can even turn out to be negative. Perhaps more robust functional forms should be used in a long run growth setting.

CHAPTER XI

STANFORD PILOT MODEL

INTRODUCTION

Principal Developers of the Model

The PILOT model was developed by the Systems Optimization Laboratory associated with the Department of Operations Research at Stanford University. The principal investigators were George B. Dantzig, Shailendrah Parikh, and Thomas Connolly. Early work was begun on the model in 1975. An initial version of the model was assembled and tested in 1976 and experimental scenarios were run during the summer of 1976. This model was expanded into what is called the "mid-1977" PILOT model. The original model and the various enhancements are described in a series of reports, including Barzelay (1977), Connolly, Dantzig, and Parikh (1977), Dantzig (1975a, 1975b), Dantzig, Connolly, and Parikh (1978), Dantzig and Parikh (1977a), Dantzig and Parikh (1976), Parikh (1977), Parikh (1976), and Parikh, Braun, and Yu (1978). Parikh (1976) probably provides the single best explanation of PILOT. Other modifications are currently being undertaken; but, at this writing, they have not been incorporated into PILOT.

Type and Complexity of Model

PILOT is a multi-time period linear program having a staircase structure. The mid-1976 model has 96 constraints and 217 activity vectors (decision variables) in each of 8 blocks. Computationally this model is considered to be of intermediate size (see White (1973)). Due

to the objective function chosen, PILOT must be viewed as a target model. Under various assumptions about the economy, PILOT indicates what "can" happen rather than what "will" happen in the future. PILOT is driven by an attempt to maximize the standard of living of the U.S. population over the time span under investigation. The standard of living is restricted primarily by the capacity of both the industrial and energy sectors of the economy. The production capacity may be increased through time via capital expenditures. A decrease in production capacity is also modeled via retirement assumptions. Given a particular set of assumptions about the future, PILOT simply determines which sectors to invest in (both energy and nonenergy) so that the standard of living will be maximized.

Sectors Emphasized in PILOT

The industrial processes of the economy are represented in PILOT by a twenty-three order input-output matrix. This matrix is an aggregate of the eighty-seven sector matrix prepared by the Bureau of Economic Analysis. The sectors are grouped as follows: five energy sectors, one agriculture sector, one nonenergy mining sector, five energy intensive manufacturing sectors, four energy nonintensive manufacturing sectors, four service sectors, and three capital formation sectors. The five energy sectors are given special emphasis.

Time Horizon

The time horizon for PILOT is eight five-year periods for a total of forty years. The eight periods represent the years 1975, 1980, 1985, 1990, 1995, 2000, 2005, and 2010. In addition to initial conditions (for

1975), PILOT also requires end conditions (for 2010) that reflect post-2010 needs. These conditions are obtained by solving a one hundred year model with several time periods aggregated into one.

Questions Addressed

PILOT is designed to measure the change in the standard of living of U.S. citizens which would result from various policy decisions available to the U.S. government, especially those affecting energy supply. These policy decisions include the following:

- The scheduling of various energy technologies to be built and used (particularly nuclear energy)
- The scheduling of various pollution abatement equipment to be installed
- The nature and the extent of conversion to equipment types that use energy more efficiently
- The required expansion of the general economy and foreign trade to supply an increasing population

PILOT also has the capability of examining the effects of reduced energy demand resulting from conservation implemented either voluntarily or through legislative means.

History and Use

EPRI (Electric Power Research Institute) is responsible for establishing priorities for research and development within the electric utilities industry. Each year, the EPRI staff develops a written report entitled "Overview" which escribes the needs of the electric utility industry, and the goals, program logic, and technical objectives which will guide the R&D activities of the Institute. During 1978, Parikh, Braun, and Yu (1978) ran several scenarios to help develop the "Overview"

plan.

ENERGY-ECONOMY INTERACTIONS

Direct

The industrial sectors of the economy are modeled by five energy producing sectors and eighteen nonenergy sectors. The five energy producing sectors place demands upon the eighteen nonenergy producing sectors for such things as crude oil pipelines, railroad shipments of coal, machinery and construction for capacity expansion, etc. These energy sectors compete with other industrial sectors for investments in capacity expansion or replacement. Likewise, the eighteen nonenergy producing segments require energy products in the form of coal, crude oil, oil products, gas products, and electricity. In addition, both sector types compete for the workforce pool to obtain the manpower needed for operation, maintenance, and capacity expansion.

Despite the seemingly all encompassing nature of these energy-economy relationships, PILOT has only been used to study a limited set of energy-economy interactions (for reasons explained in the section on evaluation). According to Parikh (1976), PILOT is best suited to measuring the impact of changes in energy availability and cost (in physical terms) on the consumption of goods and services. PILOT can also be used to study direct intervention for conservation. Parikh (1976) reports the results from five different scenarios. These scenarios reflect different assumptions about coal production limits, the availability of coal synthetics and oil shale, a nuclear moratorium, limits on imported energy and demand reductions via conservation and efficiency improvements. Dantzig,

Connolly, and Parikh (1978) demonstrate these same capabilities with three slightly different supply scenarios. Judging from both sets of results, differences in energy availability have a tremendous impact on the economy.

Indirect

PILOT forces the restriction that there cannot be a trade deficit. However, the U.S. can export wheat in order to import crude oil or gas. Thus, the trade balance constraint, which matches total exports to total imports, indirectly links the energy and nonenergy sectors. For example, if the crude oil import price or quantity or both increase, the U.S. must increase its exports in order to bring in the foreign exchange needed to pay for the imports.

STRUCTURE OF THE ENERGY SECTOR

PILOT includes five energy producing sectors in the description of the economy. These include: coal mining, crude petroleum and natural gas, petroleum refining, gas, and electricity.

Energy Resources and Extraction Costs

The primary fuel sources are coal, gas, oil, uranium, solar energy and geothermal energy. The extraction costs for all these basic sources are based on state-of-the-art technology. Therefore, PILOT determines when it becomes economically advantageous to employ any or all of the options available. PILOT has built into it the expensive recovery techniques for existing oil fields. Also, since low cost uranium reserves are extremely limited, continued development of nuclear power requires

either greater physical exploration effort (with higher cost) or technology to reprocess spent fuel from reactors, or both. The basic form of the energy sector of PILOT is displayed in Figure 11-1.

Energy Conversion

PILOT allows for eight basic types of plants for the generation of electricity as shown in Figure 11-1. These include: coal fired plants, gas fired plants, gas fired plants using coal gasification, hydroelectric plants, nuclear powered light water reactor plants, the fast breeder reactor plants, and geothermal plants. There are two types of light water reactor plants, one using enriched uranium and one using plutonium. PILOT allows for not only the enrichment of natural uranium but also the enrichment of recycled uranium. The coal fired plants may be run on either eastern coal (high BTU fuel) or western coal (low BTU fuel). Gasification of coal can also occur for either type of coal.

Prices of Energy Products

The PILOT model makes no explicit provision for the prices of energy products. Presumably shadow prices for the different constraints on energy are derived, but the model builders never mention the magnitude or behavior of these prices.

Interfuel Substitution

Interfuel substitution is allowed only in the generation of electricity. For this submodel, PILOT selects an optimum mix among hydroelectric plants, plants which use coal, oil, gas, and nuclear fuels, and plants which use solar and geothermal energy (see Figure 11-1).

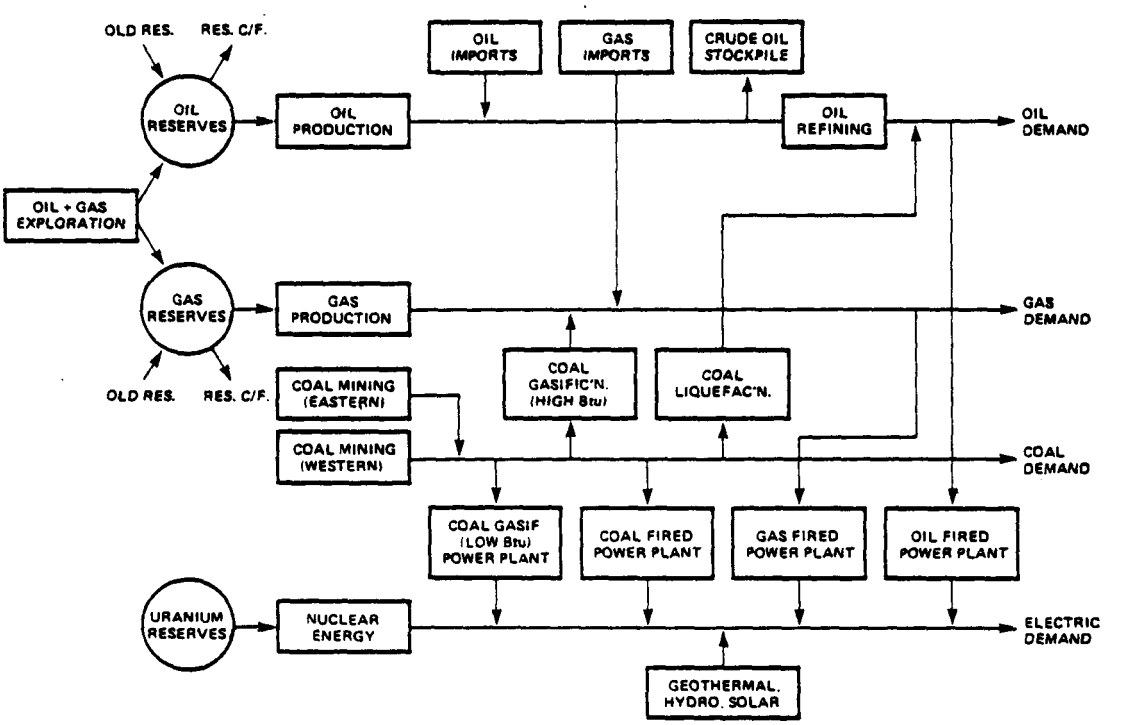


Figure 11-1. The Energy Sector of PILOT

Fuel substitution within other industrial sectors such as the energy intensive manufacturing sector is not permitted.

STRUCTURE OF THE U.S. ECONOMY

The industrial processes of the U.S. economy are represented by a twenty-three sector Leontief input-output matrix. This matrix was aggregated from a more detailed matrix prepared by the U.S. Bureau of Economic Analysis (1974) for the year 1967. The twenty-three sectors may be characterized as follows:

Energy Producing (5)

Energy Intensive Manufacturing (5)

Energy Nonintensive Manufacturing (4)

Service (4)

Capital Formation (3)

Agricultural (1)

Mining (1)

The twenty-three sectors of PILOT are presented in Table 11-1.

The activity level for the energy sectors is measured in units of BTUs or mwhs whereas the sectors associated with the nonenergy producing activities are measured in physical units. For example, the composite sector, which includes textiles, leather, clothing, and shoes, produces a composite item, abbreviated TEX, which is made up of a large variety of textile related products. This assumes that the vector of products aggregated into TEX occurs in the same proportions in the future.

Capacity constraints limit total output from the economy. Capacity available during the first period equals actual capacity in 1973 plus a

TABLE 11-1

SECTORAL AGGREGATION MAP FOR TWENTY-THREE SECTORS OF PILOT

Energy

COL	Coal Mining
CRO	Crude Petroleum and Natural Gas
ROP	Petroleum Refining
GAS	Gas
ELE	Electricity

Agriculture and Mining

AGR	Agriculture
MNG	Mining

Manufacturing (Energy Intensive)

CMP	Chemicals and Plastics
FDS	Food Stuffs
PPR	Paper Products
SCG	Stone, Clay and Glass
MET	Primary Metals

Manufacturing (Energy Nonintensive)

TEX	Textiles, Leather, Cloth and Shoes
LUM	Lumber
FAP	Furniture and Appliances
MFG	Miscellaneous Manufacturing

Services

TAW	Transportation and Warehousing
TRD	Wholesale and Retail Trade
FIN	Finance and Real Estate
SRC	Miscellaneous Services

Capital Formation

TRE	Transportation Equipment
MAC	Machinery
CON	Construction

portion of new construction. Parikh (1976) discusses some of the difficulties in estimating capacity. Capacity is generally estimated by dividing output by some index of capacity utilization. The PILOT group derived 1973 output from 1967 input-output transactions data and the Federal Reserve Board Production indexes. Two sets of capacity utilization indexes are used for the manufacturing and mining industries. One is taken from the Wharton capacity utilization index; the other is based on a joint evaluation and analysis of McGraw-Hill and Bureau of Economic Analysis surveys. Capacity estimates for the other industries were developed from average capacity utilization indexes for the manufacturing and mining industries. In the PILOT model a capacity factor of .9 is used. This implies that the maximum output that can be sustained over any future five-year period equals 90% of available capacity.

Factors of Production and Substitution Possibilities

No distinction is made in the PILOT model between different vintages of capital. For the nonenergy sectors, a construction lag of two years is assumed. As a result, 20% of the total capacity addition initiated in any period becomes available in that same period with the remaining 80% coming on-line in the following period.

The labor-force is divided into two groups: agricultural and nonagricultural. The nonagricultural component accounts for 96% of the total workforce and can be distributed in any way among the twenty-two nonagricultural sectors. The agricultural workforce cannot be employed in nonagricultural uses.

Because of the fixed coefficients in the PILOT model, no substitution possibilities exist in the nonenergy sector between capital, agricultural

labor, nonagricultural labor, energy, and other sectoral outputs.

MACROECONOMIC STRUCTURE

Like the Glassey-Benenson (Berkeley) model, PILOT lacks the well-defined macroeconomic structure provided by a growth model. Instead, PILOT is "driven" by a dynamic linear programming formulation. This optimization procedure determines the all-important split between consumption and investment. It does so by allocating industrial output to consumption and capital formation in such a way as to maximize per capita consumption (subject to some constraints) over the planning period.

This maximization of per capita consumption appears relatively straightforward, at least until one realizes that there are no prices in the PILOT model. Without prices, the model builders must find an alternative scheme for assigning value weights to different types of goods. (Without value weights, even the maximization of consumption of apples and oranges becomes impossible.) Avril (see Dantzig, Connolly, and Parikh (1978)) describes this weighting scheme in a section on consumption functions. Essentially, the PILOT group uses the following procedures to determine average consumption profiles,

(1) Using personal consumption expenditure data on ten income groups, regress per capita consumption in sector i on per capita consumer income before taxes $(y_i = a_i x^{b_i} + c_i)$.

(2) Use the equation estimated in step 1 to compute consumption expenditures for any consumer group (defined by its per capita income) for assumed changes in income.

(3) Compute the weighted average consumption level for each sector corresponding to each assumed change in income $(\bar{y}_i^{67}(d_\ell))$.

The weights are the fractions of the population in each consumer group.

(4) Adjust the average consumption determined in the preceding step to 1967 levels.

(5) Estimate the relationship between these 1967 average consumption figures $(\bar{y}_i^{67}(d_\ell))$ for each sector and average total expenditure $(\bar{y}_i^{67}(d_\ell) = \gamma_i M + \delta_i)$ over the different changes in income (d_ℓ).

(6) Use the parameters from step 5 to constrain personal expenditures in each future five-year period. $(y_i^t = \gamma_i M^t + \delta_i)$. By definition the sum of the 1967 average consumption figures equal average total expenditure, so the γ_i must sum to one and the δ_i to zero.

Capital formation takes place in the PILOT model in the same rigid fashion as consumption. It is discussed in detail in a later section on model evaluation. PILOT distinguishes and keeps separate account of the capacities of the eighteen nonenergy sectors. In any five-year period, the linear model allows for adding any amount of capacity to any of these sectors, subject to the constraint that the industrial output is available for such addition and expansion. Due to the retirement of equipment and structures, the capacity of each of the eighteen nonenergy sectors is depreciated at the rate of 20% per five-year period. As was mentioned earlier, the initial capacities are set at the 1973 level adjusted to 1975.

The import-export component connects the U.S. economy with the rest of the world. The model simply requires that total exports exceed total imports. Hence, the U.S. economy can trade its excess output in the agriculture sector to reduce shortages in the energy sectors (primarily oil and gas). Imports and exports of energy are accounted for in units of BTUs and their prices are determined by input constants.

The import/export component of PILOT is modeled via four basic types of constraints:

- A balance of trade constraint requires that the U.S. have a favorable trade balance. That is, the sum of all exports must not exceed the sum of all imports.

- An export constraint allows any level of exports along a curve derived from export elasticities. The basic principle modeled is that increases in exports bring smaller and smaller increases in revenues.

- There are upper bounds on imports.

- The change in both imports and exports during a five-year period is restricted.

Government consumption is assumed to be at a fixed rate of GNP (for most runs this is 34%).

GROWTH AND TECHNICAL CHANGE

Productivity in the nonenergy sectors is assumed to increase at the rate of 2% per year in order to account for technological change. Within the energy sector, the fast breeder reactor is assumed to be available for commercial use by the year 2000. PILOT also allows for some unspecified new technologies to be used after the year 1990. Assumptions are made about the costs of using these technologies as well as bounds on the amount of energy available.

METHOD OF SOLUTION

PILOT is a linear program having approximately 800 rows and 2000 columns. The constraint matrix has a staircase structure (see Figure 11-2) which has historically proven to be quite difficult to solve, frequently requiring ten times the number of pivots generally required for other problems of the same size. The PILOT research team has been running PILOT on the Stanford Linear Accelerator Computer System, which consists

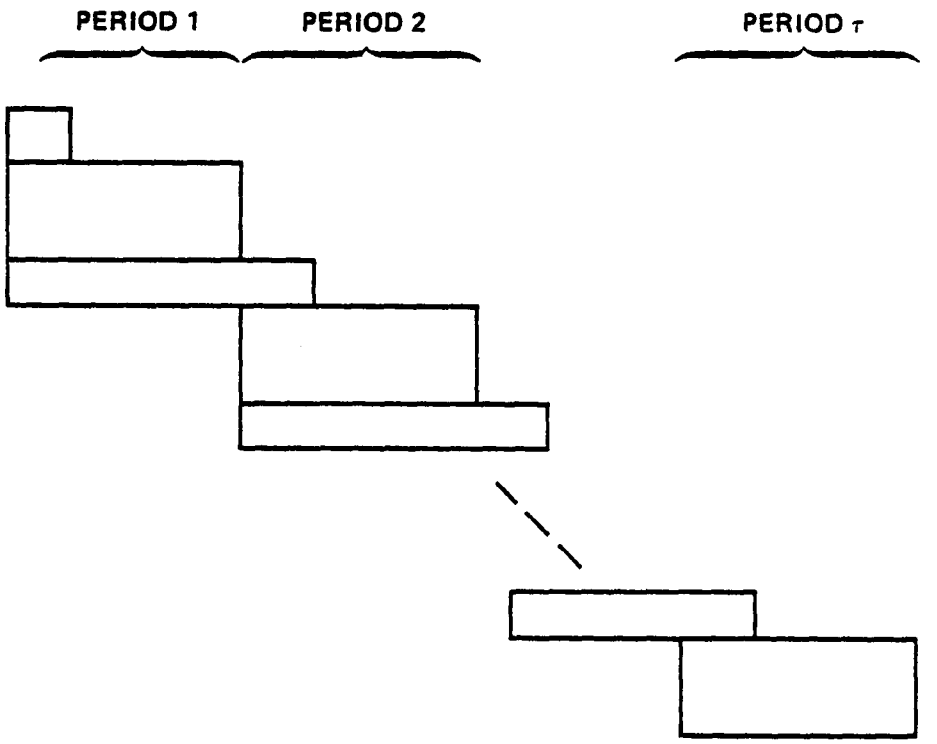


Figure 11-2. The Dynamic Staircase Structure of PILOT

of a system of three IBM 370's. The Wylbur Text Editor is used to modify the data for various runs. The constraint matrix is generated by the MAGEN system developed by Haverly Systems. The basic linear programming system is Management Sciences' MPS 3.

The System Optimization Laboratory is also beginning experiments with two specialized techniques for solving PILOT. They involve price-directive decomposition (also called Dantzig-Wolfe decomposition) and the primal partitioning algorithm (also called generalized GUB). Results with these algorithms have not been reported at this writing.

EVALUATION OF MODEL

A recent EPRI report (see Baughman, et al. (1978)) summarizes the major shortcomings of the PILOT model. Without a doubt the greatest weakness of the PILOT model stems from its reliance on fixed coefficients. These fixed coefficients completely rule out the possibility of factor substitution in the production process, regardless of the price of energy. This is an extremely serious omission in a model designed to assess the long-term (40 to 100 years) impacts of increasingly limited supplies of energy.

This lack of substitution possibilities in the production process is compounded by the failure to allow final demand to respond to prices. Again, regardless of energy prices, the composition of final demand remains unchanged. Of course, in reality, as energy prices climb higher consumers can be expected to shift to less energy-intensive goods.

The only substitution allowed in the PILOT model occurs within the energy sector. But this substitution is limited to the choices of tech-

nologies within a given fuel sector.

There are other problems with PILOT not mentioned in the EPRI report. Perhaps most important is the very general specification of capital formation. The same capacity expansion coefficients are used for all nonenergy sectors, thereby creating a serious aggregation bias. Moreover, the inputs of goods and services required for capital expansion are simply prorated across all sectors (both energy and nonenergy). Finally, capital formation is chosen solely on the basis of maximizing consumption across all periods. In order to avoid a feast-or-famine situation, several arbitrary constraints are added to the model -- average per capita consumption must be non-decreasing over time, and a lower limit is imposed on first period consumption and on final-period capital formation. But even with these constraints capital formation in the PILOT model remains an essentially noneconomic phenomenon since rates of return, capital productivity, different vintages of capital, risk, etc., all go unheeded. This more or less arbitrary determination of final demands carries over to the international trade sector. In marked contrast to reality, the U.S. is not allowed to run a balance-of-trade deficit. Moreover, imports appear to be unstable, fluctuating greatly from scenario to scenario.

Perhaps the best evaluation of PILOT comes from EPRI (see Baughman, et al. (1978, p. 3-13)), one of the agencies funding the development of the model:

> The principal strength of the PILOT model thus lies in its ability to analyze the choice among supply technologies within each fuel category. The main area of application of the model is in the appraisal at a national level of broad technological options. The weaknesses of the PILOT model with regard to its treatment of the energy system as a whole, of energy-economy interaction, and of the functioning of the general economy limits its usefulness as a model for integrative analysis.

CHAPTER XII

WHARTON ANNUAL ENERGY MODEL

INTRODUCTION

Principal Developers of the Model

The Wharton Annual Energy model represents a substantial modification of the Wharton Annual model, a large-scale macroeconomic model of the U.S. economy. The modification was performed by Wharton EFA under the direction of Lawrence Klein and funded by the Electric Power Research Institute (EPRI).

Type of Model and Submodel

The core of the Wharton Annual Energy model (hereafter referred to as the Wharton Energy model, or more simply still as the Energy model) is an elaborate input-output table consisting of sixty-three sectors. The coefficients in the I-O table are flexible, a substantial improvement over the fixed coefficients in most models. The Energy model also contains (is linked to) a number of satellite energy models. According to a Wharton EFA report (1978), these include the Wharton Coal Satellite model, the Pseudo Data Electric Utility model developed by Griffin (see Griffin (1976, 1977)), and the residential energy demand section of the Federal Energy Administration PIES model. The Energy model retains basically the same macroeconomic structure as the Wharton Annual model. This macroeconomic structure consists of eight major blocks: final demand, labor requirements, wage rates, value-added prices, wholesale prices, final demand prices, income payments, and the financial sector. The structure of the

Annual model is flow charted in Figure 12-1.

Complexity

With its large I-O table, detailed macroeconomic structure, and satellite energy models, the Wharton Energy model ranks as one of the most complex energy-economy models.

Sectors Emphasized

The Wharton model builders take a very balanced approach to the study of energy-economy modeling. All three of the components of an energy-economy model -- the energy sector, the structure of the economy, and the macroeconomic structure -- are equally well represented.

Time Horizon

According to Preston (1975), the Annual model is designed for intermediate term projections (5 to 10 years). However, the Energy model has already been used to make long-term forecasts (to the year 2000). Given the initial objectives of the model builders, this may be stretching the capacities of the model.

Types of Questions Addressed

The Energy model has been used to simulate the impacts of a BTU tax for the Sun Company (Wharton EFA (undated)), a BTU tax, high and low growth in residential electricity demand, and the National Energy Plan for EPRI (Wharton EFA (1978)), and an oil embargo for the Macroeconomic Analysis Division of the Energy Information Administration (see Wharton EFA (undated) for a description of the methodology used).

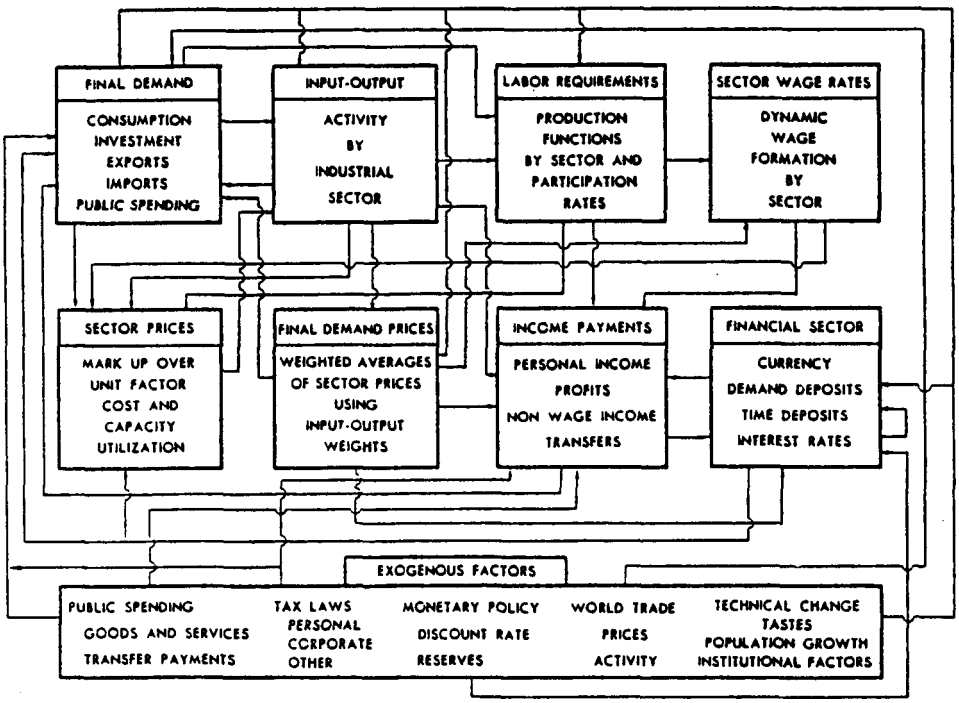


Figure 12-1. Flow Chart of the Wharton Annual Model

Source: Preston (1975, p. 4).

ENERGY-ECONOMY INTERACTIONS

At first glance, the Wharton Energy model seems ideally suited for analyzing all types of energy-economy interactions. In reality its capabilities are limited by its value-added pricing structure and the absence of a growth model. (Although Wharton EFA appears to be attempting to remove these limitations, the basic structure of the model probably places upward bounds on these efforts.)

STRUCTURE OF THE ENERGY SECTOR

According to Baughman, et al. (1978), the energy sector of the model consists of eight different energy industries: coal mining, crude petroleum and natural gas liquids, natural gas, petroleum refining and related industries, electric utilities, gas utilities, Federal electric utilities, and state and local electric utilities. At the present time coal and electric utilities are represented by detailed submodels. The other industries are portrayed by single columns in the I-O table.

Energy Resources and Extraction Costs

The primary energy sources are coal, crude petroleum and natural gas liquids, and natural gas. Since crude petroleum and natural gas liquids and natural gas are produced in fixed proportions, these industries are represented by a single column in the I-O table and disaggregated only by rows (see Glassey and Benenson (1975a, 1975b) for a detailed discussion of this procedure).

Apparently no detailed description of the Wharton Coal Satellite model is available. However, Wharton's 1978 report on the energy model

carries a very brief summary. The macro model provides the coal model with the following information:

- electricity generated by fossil fuels
- output of crude steel
- output of clinker
- prices of alternative fuels
- prices of material inputs

The coal model in turn provides the macro model with the following variables:

- constant dollar value added in coal
- coal output in tons
- coal exports
- coal prices
- wage bill in mining
- employment in coal mining
- real investment in coal mining

According to Wharton EFA, the input mix determined in the satellite coal model is not completely consistent with the detailed I-O table in the macro model.

Energy Conversion and Distribution

The electric utilities industry is modeled with a pseudo data electric power cost function developed by James Griffin. Griffin (1976, 1977) explains this cost function in some detail. He begins with a linear programming (industrial process) model describing the technical coefficients in the production of electricity. The LP model shows the input configurations needed to produce a given output at minimum cost. So far, there

is nothing unusual about this approach to adding to the flexibility of the I-O table. (For example, see Glassey and Benenson (1975a, 1975b)). Griffin's contribution lies in his using the LP model to trace out a number of optimal input configurations corresponding to different input prices, holding output constant. He then fits a statistical cost function to these factor combinations and prices, i.e., pseudo data. Finally, he derives the optimal long-run input-output coefficients from this cost function. (See Hudson-Jorgenson (1978c) or Brock and Nesbitt (1977) for a detailed description of this last procedure.)

Griffin's input-output coefficients possess several advantages over those derived by Hudson and Jorgenson from conventional time-series data. Perhaps most important, they are not obtained from historical data showing only limited price fluctuations or technological changes. In addition, new technologies or environmental constraints can be introduced into the LP model and, in turn, into the I-O coefficients.

The energy sector also contains four other conversion and distribution sectors, each portrayed by a single column in the I-O table: petroleum refining and related industries, gas utilities, Federal electric utilities, and state and local electric utilities.

Prices of Energy Products

According to a 1978 Wharton report, the price determination mechanism in the third version of the Annual model and Energy model is based upon a value-added relationship. This implies that unit capital costs and unit labor costs determine the value-added deflator for each intermediate sector. The deflators for the different components of GNP are then derived as weighted averages of the intermediate value-added deflators. The

weights come from the I-O table.

Because of their value-added pricing structures, energy prices in the Wharton models (Annual and Energy) do not directly reflect the cost of energy. Instead, these prices depend only upon labor and capital costs and the input-output coefficients. For this reason, there is considerable doubt about whether or not the Wharton models can capture the full impact of energy price changes on the economy.

Interfuel Substitution

Substitution among the various inputs to an industry, including all fuels, are governed by the exact same elasticity of substitution. Griffin (1976) points out the severity of this assumption by noting (p. IV-4) that this amounts to assuming that "the substitution relationship between coal and fuel oil is ... the same as between natural gas and the paper clips consumed in the front office" of an electric utility.

For this reason, the electric utility model plays a key role in interfuel substitution. Wharton EFA compares the simulation results from the fully linked electric utility model to the input-output coefficients computed in the interindustry model. The comparative results are presented in Table 12-1. Despite very large assumed price increases during the period 1975 to 1981, the standard I-O coefficients show very little change. Indeed, some of these coefficients behave almost perversely. For example, the I-O coefficients for natural gas increase despite a 174.7% increase in gas prices during the period 1975 to 1980.

STRUCTURE OF THE ECONOMY

In the Wharton Energy model the economy is portrayed by a sixty-

TABLE 12-1

COMPARISON OF THE I-O COEFFICIENTS FOR THE ELECTRIC COLUMN GENERATED BY THE ELECTRIC UTILITY MODEL (EUM) AND BY THE STANDARD WHARTON PROCEDURE (SWP)

	Coal*		Natural Gas		Fuel Oil		Nuclear	
	EUM	SWP	EUM	SWP	EUM	SWP	EUM	SWP
1975	2.188	1.675	3.559	3.819	1.248	1.345	.120	.112
1980	2.280	1.739	0.792	4.070	1.731	1.329	.695	.112
1985	1.793	1.711	0.0	4.156	2.478	1.334	1.700	.112
1990	1.340	1.668	0.0	4.212	3.020	1.338	2.833	.112

*Coefficients x 100

Source: Wharton (1978, p. 36).

three sector input-output table. Eight of these sectors are energy related, the other fifty-five represent the rest of the economy. The I-O coefficients are all expressed in dollar terms rather than BTUs.

Unlike most I-O models, the Wharton Annual model and the Energy model can be updated yearly (instead of every five years or more). This is possible because the Wharton I-O models are based upon GNP originating by industry (value added) rather than gross output. However, this ability to reproduce published annual output data comes at a considerable cost in complexity. According to Griffin (1976), the basic I-O relationship governing the model can be expressed as follows:

$$Z = B(I-A)^{-1}HG$$

where Z is the vector of "gross" value added originating by industry (there are sixty-three industries), B is a diagonal matrix of the ratios of value added by gross output, A is the matrix of technical coefficients, I is an identity matrix, G is the vector of final demands, and H is a bridge matrix which translates final demand by GNP component (shown by G) into final demand by industrial sectors. The bridge matrix is necessary because there are fewer final demands than industries.

Substitution Possibilities

Wharton EFA has devoted considerable effort to making the I-O coefficients price responsive rather than fixed. Again, the only detailed treatment of their techniques is provided in non-Wharton publications by Griffin (1976) and Baughman, et al. (1978). (Preston (1975) discusses the approach taken in the Annual model.)

According to Baughman, et al. (p. 3-8), "The relationships determining the input-output coefficients in the Wharton model are derived

from constant elasticity of substitution production functions for each industrial sector." In other words, all inputs must have the exact same elasticity of substitution. Moreover, the production functions include only materials inputs. Capital and labor are estimated elsewhere in the model. Judging from the results presented in the section on interfuel substitution, the I-O coefficients display a very slow speed of adjustment and a negligible price substitution term.

MACROECONOMIC STRUCTURE

With the exception of increased sectoral detail, the macroeconomic structure of the Energy model is virtually unchanged from that of the Annual model. There are thirty-two investment sectors (capital formation), fourteen consumption sectors, six government sectors, and fourteen trade sectors. The capital formation equations are basically neoclassical in design with output, price, and user cost as the major variables. Consumption is determined primarily by income, prices, wealth, credit conditions, and tastes. Government spending and the international sector are not discussed in any of the publications available on the Wharton Energy model.

The labor requirements sector of the energy model covers twenty-eight different categories -- sixteen manufacturing, and twelve non-manufacturing. Labor requirements are calculated by renormalizing production functions on labor or man hours with capital stock, output, and technological change on the righthand side of these equations. The unemployment rate equals the difference between aggregate labor requirements and aggregate labor supply (determined by participation equations). Wage

rates depend upon price trends, productivity, and labor market conditions. Wage rates are first determined for the leading "sectors" and then for the remaining sectors.

Interest rates are derived in the monetary sector. This sector contains equations and identities for estimating commercial bank demand deposits, currency, commercial bank time deposits, the prime commercial paper rate, and the bond rate. The prime commercial paper rate is determined by free reserves and the discount rate. Long-term interest rates are calculated through term structure equations relating changes in long-term interest rates to a lag distribution in changes in the prime commercial paper rate.

METHOD OF SOLUTION

According to Wharton EFA (1978, p. 20), "The structural relationships of the model are simultaneous rather than recursive; ... multiple iterations are necessary to achieve convergence for a given year." Baughman, et al. (1978, p. 3-6) summarize the solution procedure as follows:

> Starting with estimates of the major final demand components (consumption, investment, etc.) the standard input-output arithmetic is used to calculate the output in each of the 59 industrial sectors. Next, prices, wage rates, and labor requirements are computed, and these, in turn, determine income payments such as personal income, profits, etc. A model of the financial sector generates estimates of money supply and interest rates. Industrial labor requirements are used to derive estimates of total employment and unemployment.

Figure 12-2 presents a simplified flow diagram of the Wharton Energy model.

EVALUATION

Our review of the Wharton Energy model has been handicapped by a

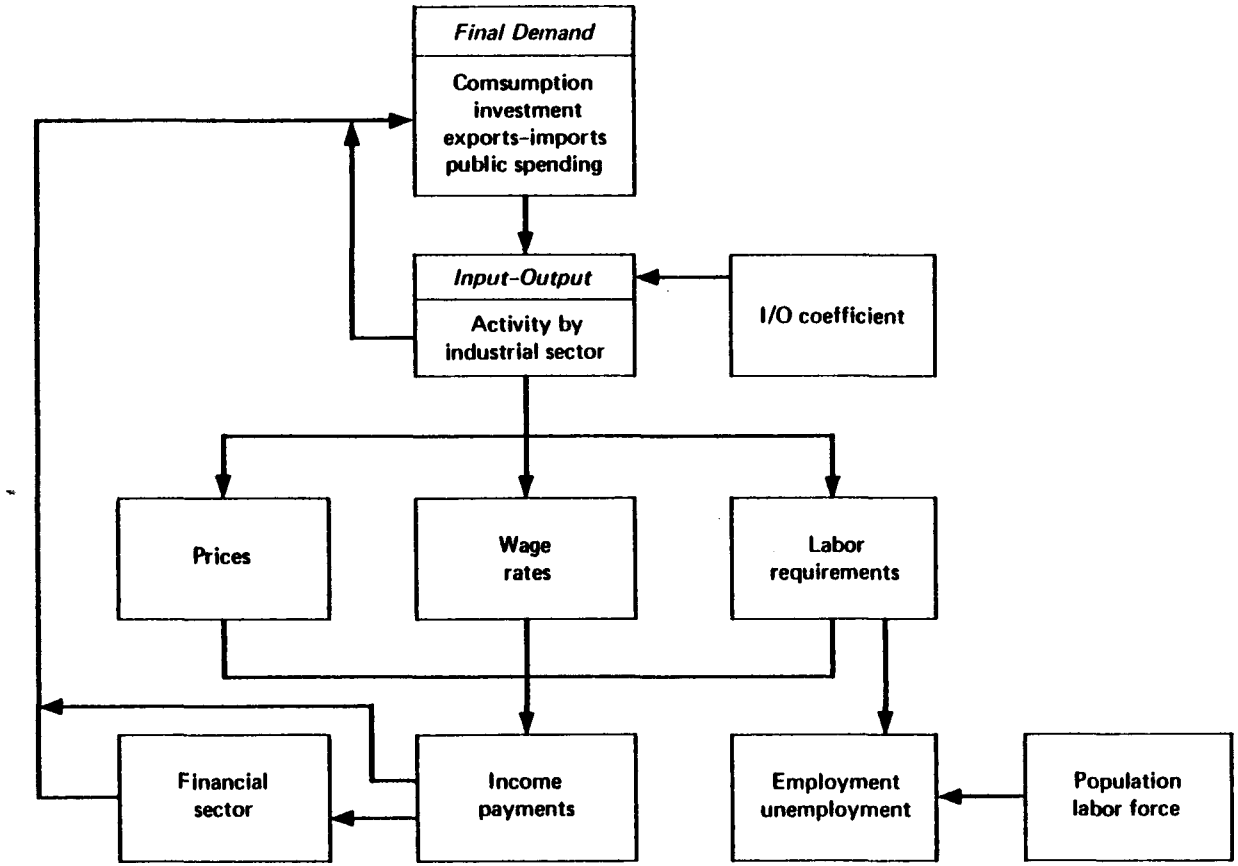


Figure 12-2. Simplified Flow Diagram of the Wharton Energy Model

Source: Baughman, et al. (1978, p. 3-7).

lack of model documentation. So, too, is our evaluation. Moreover, the Wharton Energy model appears to be in a continual state of revision, making our task still more difficult.

This state of revision apparently reflects considerable dissatisfaction with some of the properties of the Wharton Energy model. An NBER review (cited in Baughman, et al. (1978, p. 2-25), but no documentation available) for EPRI concludes that "Unfortunately, we have serious reservations concerning the model's ability to analyze scenarios involving changes in energy conditions or energy policies. The problem as we see it focuses on the way in which prices are handled in the Wharton model." The NBER review continues as follows:

> The structural price equations in the Wharton model are used to explain value-added prices. The wholesale and final demand prices are then derived from the value-added prices using accounting identities. There are several difficulties in using this approach. First, the value-added prices are theoretical constructs which do not correspond to any observable market prices in the real world. Furthermore, because of the way in which they are constructed, value-added prices often move in ways which are counterintuitive. An example of this, cited by Wharton at the January 4-5 EPRI meeting, is that value-added petroleum prices have been declining recently, while market prices for petroleum have increased sharply. This type of behavior makes it very difficult to evaluate the reasonableness of the structural parameters in the price equations.

NBER goes on to say that another difficulty is that value-added prices are based on capital and labor unit costs (and market conditions), but do not directly reflect materials costs. Moreover, there are other deficiencies in the specification of the pricing system of the Wharton model. These have already been mentioned in our section on substitution of factors. Baughman, et al. go on to say that the model does not relate the demands for capital and labor to their supplies. This apparently poses serious problems for long-run analysis. In particular, there is

no guarantee that output is consistent with productive capacity. Baughman, et al. conclude that the Wharton Annual Energy model, while perfectly satisfactory as a short-run forecasting model, is not well suited to long-run forecasting or to analyzing the interdependency between fuels in the energy system or between the energy system and the rest of the economy. Their contention appears to be supported by results reported in both Wharton EFA (1978) and Wharton EFA (undated) on energy tax analysis. In particular, the Wharton simulation results show almost no impact of a large change in energy prices on GNP. Moreover, the impact on price levels is not very large.

CHAPTER XIII

REISTER-EDMONDS TWO-SECTOR MODEL

INTRODUCTION

Reister and Edmonds (1977) refer to their energy model as the two-sector model. Appropriately enough, the model consists of an analysis of a two-sector economy--one representing energy and the other the rest of the economy. The total output in each sector depends upon inputs of capital, labor, energy, and materials. The rest of the economy sector is described by a linearly homogeneous production function; the energy sector, by a collection of activities or processes with resource constraints.

Rather than estimate the parameters of their model, Reister and Edmonds simply assign values to these parameters. They then use their model to forecast energy demand and GNP for the single year 2000.

ENERGY-ECONOMY INTERACTIONS

The Reister and Edmonds model has been used to study the following energy/economy interactions:

- The effect of constraints on the energy supply on GNP and the price level.
- The impact of higher energy prices on GNP and the price level.

STRUCTURE OF THE ENERGY SECTOR

Energy Resources

Reister and Edmonds (R-E) assume that the energy sector is characterized by decreasing returns to scale (because of resource limitations)

and imperfect competition. In order to capture the decreasing returns to scale, R-E model the energy sector as a collection of processes, each constrained by a maximum production rate. These processes describe various ways of producing four energy carriers--electricity, oil (liquids), gas (gases), and coal (solids). Each process produces one energy carrier from inputs of capital, labor, materials, and energy carriers. Judging from one of their tables (1977, Table 7), there are at least thirteen different processes. A linear program determines the optimum set of possible processes. This optimum combination of processes is designed to satisfy the constraints and to provide for the total demand for energy at the least possible cost.

After creating a theoretical model of the energy sector, Reister and Edmonds then jettison much of this model. For example, the model builders announce (p. 224) that "In our numerical work, we have chosen to simplify further the energy sector by assuming that each process...turns factors of capital, labor, and materials directly into a carrier without consuming any other energy carrier." R-E also note that the dual solution to the linear programming problem yields the marginal cost for each energy carrier. However, they set the price of aggregate energy equal to its average cost rather than to its marginal cost.

After determining the optimal "solution" from the linear programming problem, R-E then calculate the input-output coefficients for the energy sector. Reister and Edmonds use data from the 1967 input-output table to determine the input-output coefficients in their model. They aggregate these data into the broad sectors of their model.

Rather than estimate the coefficients of their energy production

processes, they base these coefficients on "1967 I-O coefficients for the energy sector (see Table 5), a brief review of the literature, and the average cost for each production process in 1975 dollars." Despite the substantial increase in the price of fossil fuels during the period 1967-1975, R-E also announce their intention to assume no further increases in relative prices, leading them to term their energy price assumptions "optimistic."

Energy Conversion and Distribution

Reister and Edmonds do not report all the energy production processes available in their model. However, it does appear that they have included the following processes: Coal and hydro electricity, nuclear electricity, solar electricity, synthetic oil, and synthetic gas. These processes are modeled with the same simplicity as oil, gas, and coal.

Prices of Energy Products

Prices of individual sources of energy are never explicitly discussed in the two-sector model. These individual prices appear to play no role in either the production processes or in the demand for energy. Instead Reister and Edmonds set the price of energy equal to its average cost. This average cost is determined by the model conditional upon the authors' estimated average cost of each production process in 1975.

Interfuel Substitution

The two-sector model makes no explicit provision for interfuel substitution. Instead, the demand for each energy carrier (electricity, oil, coal, and gas) is assumed to be strictly proportional to total energy de-

manded by the rest of the economy. This assumption of strict proportionality in use rules out the possibility of interfuel substitution on the demand side. It also implies that the elasticity of demand for each carrier is zero, i.e., the same amount will be consumed regardless of price. Reister and Edmonds never state how they determine these proportionality factors.

However, interfuel substitution is possible on the production side. This substitution is very limited since it only applies to the different processes used to produce a particular carrier. For example, electricity can be produced by means of coal, hydro, nuclear, or solar techniques.

STRUCTURE OF THE U.S. ECONOMY

Level of Aggregation

Reister and Edmonds view the rest of the economy as a single sector, a so-called "materials" sector. This sector is described by a structural matrix consisting of input-output coefficients for capital, labor, energy, and materials.

Like Hudson-Jorgenson, Reister and Edmonds base these input-output coefficients on a production function approach. Invoking Shephard's lemma, they make the transition from a production function to a price possibility function. Unlike Hudson-Jorgenson, they do not elect to use a translog function. Instead, they devise a new function which they term a generalized CES function. By using this type of function, they hope to avoid the possibility of negative I-O coefficients which sometimes arise with a translog function.

According to Reister and Edmonds, their generalized CES price possi-

bility function possesses all of the following properties: constant returns to scale, all parameters greater than or equal to 0, and quasi-concavity. The input-output coefficients are derived by taking the first partial derivatives of this price possibility equation. These derivatives are extremely complex.

Apparently Reister and Edmonds never solve for the values of these parameters, probably because there are so many of them (and so few ways to eliminate degrees of freedom). Instead, they assign values to the parameters, stating that the values "were selected after a modest testing program" on the basis of assumptions.

Factors of Production

The factors of production are capital, labor, energy, and materials. No assumptions are made about capital vintage, stock adjustments, etc.

Substitution Possibilities

The I-O coefficients in the materials sector are determined by factor prices. As a result, substitution possibilities do exist among labor, capital, materials, and energy. Because of the complexity of the "generalized CES function" used by Reister and Edmonds to model the price possibility frontier, the elasticities of substitution are difficult to compute. Reister and Edmonds never state the magnitude of these elasticities.

MACROECONOMIC STRUCTURE

Investment never explicitly enters the two-sector model. Reister and Edmonds justify this exclusion by saying (p. 237) that "we are taking a snapshot of the economy in the year 2000...." Instead of focusing on

investment, Reister and Edmonds specify that capital is related to GNP by a capital-to-output ratio. This capital-to-output ratio is assumed to equal $s/(\mu+g+\delta)$ where s is the rate of savings, μ equals the rate of growth of labor productivity, g is the rate of growth of man hours, and δ is the rate of depreciation. Reister and Edmonds then set s = 15.15%, μ = 2%, g = .61%, and δ = 5.2%. These assumptions imply a growth in the capital-output ratio to .48 from .4074. (In the model the units of κ are 1967 dollar's worth of returns to capital per 1967 dollar's worth of GNP.)

Reister and Edmonds never explicitly mention the determinants of consumption, nor does consumption appear as a variable in their model. However, consumption implicitly equals one minus the savings rate(s) times net output.

In most models of energy and the economy, the macroeconomic structure serves to determine the final demand for goods and services and various factor prices. However, Reister and Edmonds provide no macroeconomic structure to their model.

GROWTH AND TECHNICAL CHANGE

Demographics

The labor input to the two-sector model is measured by the total hours worked by employees in the year 2000. Reister and Edmonds assume a labor force of 120.8 million and then calculate the average hours worked per employee with a linear regression on historical data for 1948-1975. They also assume a military force of two million people and an unemployment rate of 4.3%. The value of total labor services is then developed by calculating an hourly labor rate from the 1967 data and increasing this rate by

2% per year to reflect the assumed growth rate in labor productivity.

Technical Change and Productivity

Reister and Edmonds base their calculation of the capital-output ratio upon the assumption of Harrod-neutral technological change.

Capital Stock Adjustment

Not mentioned.

Real Rate of Return to Capital

The real rate of return equals the marginal product of capital from the production function.

METHOD OF SOLUTION

The two-sector model contains two sets of balancing equations. The first set equates inputs of each factor of production to outputs to each sector. For example, total labor services equal the labor services used in producing energy and materials. These equations are also expressed in terms of input-output coefficients, thereby adding four more balancing equations to the accounting system.

Reister and Edmonds call their second set of equations price-cost balance equations. Reister and Edmonds set the prices of energy and materials equal to the factor prices times the input-output coefficients for these factors of production.

Reister and Edmonds apparently produce values of energy-economy aggregates from their model as follows:

1) Set labor, factor prices, and the input of energy to the material sector at starting values.

2) Determine the values of the I-O coefficients in the material sector. At the same time solve for the I-O coefficients in the energy sector. Do so by assuming a strict proportionality between the demand for each energy carrier and the predetermined value of energy input to the materials sector. Given these assumed demands and assumed I-O coefficients for each process, the linear program provides the values of total energy output, capital, energy, and materials inputs to the energy sector, and all four energy sector I-O coefficients.

3) Once the energy output and I-O coefficients are known, calculate the materials output from the energy balance equation or the labor balance equation (now expressed in terms of input-output coefficients).

4) With the outputs of both sectors in hand, use the materials balance equation and its input-output coefficients to produce a value for GNP.

5) Given the value of GNP and the assumed value of the capital-output ratio, compute the amount of capital services. Or compute this value from the capital services balancing equation.

6) Use the price-cost balancing equations to compute the prices of materials and energy.

7) Use the energy balancing equation to compute a new value of energy input to the material sector.

8) If the computed prices of energy and materials and the energy input to materials are not equal to the starting values, solve the three parts of the model (energy sector, materials sector, and accounting system) iteratively.

EVALUATION OF MODEL

Capabilities

With time most people come to take even the most impressive technological changes for granted. The Wright brothers' flight at Kitty Hawk shocked the world; today's jumbo jets scarcely arouse our interest let alone our curiosity.

The Reister-Edmonds two-sector model serves an important purpose--it helps us appreciate our energy modeling technology. The model does

so because, despite the sincere efforts of Reister and Edmonds, it cannot fly.

Reister and Edmonds discuss their work with an unusual degree of candor for model builders. Perhaps that is why the shortcomings of their model are so apparent. These shortcomings can be summarized as follows (not necessarily in degree of importance):

- Setting energy prices equal to average cost rather than marginal cost biases energy prices downward, thereby biasing energy use upward.

- Some of the results appear to be counter intuitive. For example, the energy/GNP ratio is greater for the constrained supply scenario than for the unconstrained scenario. There is a "surplus" of capital in the year 2000 (judging from the relative price of capital). Energy prices actually drop in the unconstrained supply case. Moreover, energy prices are lower in the lower demand elasticity case (.25 vs. .75).

- Much of the model is based upon a new and untested price possibility function (referred to by Reister and Edmonds as a generalized CES function). This function is so complicated that Reister and Edmonds find it impossible to estimate. Instead, they arbitrarily assume values for the parameters of a greatly simplified and very restrictive version of the function.

- The price-cost balance equations equate the price index to a weighted average of factor price indexes. These equations are used to solve for the price of energy and materials, thus setting price equal to average cost rather than marginal cost. Moreover, Reister-Edmonds' use of indexes rather than prices invalidates even these results.

- The demand for each type of energy in the model is assumed to be strictly proportional to total energy demand, regardless of the price of each type of energy.

- The amount of capital, labor, energy and materials used in any energy process are fixed, regardless of relative prices. The capacity constraint for each process is also fixed, regardless of price and time period.

- The model possesses no macroeconomic structure. As a result, all final demands must be assumed. Moreover, there are no real interactions between the energy sector and the economy.

- There appears to be no mechanism for solving the model. The final results are both inconsistent and arbitrarily selected.

- All results are produced from assumed relationships based upon historical data rather than from engineering and/or economic relationships.

Uses

The Reister-Edmonds model cannot be used in its present form.

CHAPTER XIV

BERKELEY (GLASSEY-BENENSON) MODEL

INTRODUCTION

Principal Developers of the Model

The Berkeley model was developed by the Energy and Environmental Division of the Lawrence Berkeley Laboratory and the Operations Research Center of the University of California at Berkeley. The principal investigators were C. Roger Glassey and Peter Benenson. The model is described in detail by Glassey and Benenson (1975a, 1975b).

Type of Model and Submodels

The model is a linear program whose basic component is a ninety-seven-sector input-output matrix. The outputs of the energy producing sectors are measured in terms of BTUs or mwhs, the outputs of the other sectors are expressed in dollars. Two of the sectors, electric utilities and iron and steel, contain submodels which allow these industries to be modeled in greater detail. In particular the submodels permit inter-fuel substitution within these two energy-intensive sectors.

All relationships are assumed to be linear and the model is restricted to a single time period. The basic model has approximately three hundred activity vectors and one hundred constraints.

Time Horizon and Questions Addressed

The model is designed to determine the economic impacts of fuel and energy shortages, such as the Arab oil embargo of 1973. Fuel substi-

tution within the electric utility and the iron and steel industries partially compensates for shortages of certain fuels.

The model has also been used to examine energy use in 1980 and 1985. In making these forecasts, Glassey-Benenson assumed that the production technology remained the same as in 1972 and simply increased the capacities of the activity vectors to reflect the estimated growth.

ENERGY-ECONOMY INTERACTIONS

The Berkeley model was specifically designed to study the economic impacts of energy shortages. Glassey and Benenson use the model to measure the impact of shortages on industrial production by sector, total employment, and GNP.

This focus on "shortages" is not as restrictive as it sounds. As Glassey-Benenson point out, a shortage can stem from a sudden supply cutback like the Arab oil embargo or from the failure of the energy sector to keep pace with the rest of the economy. This slower growth can result from resource depletion, a moratorium on nuclear plant construction, manpower shortages, bottlenecks, etc.

STRUCTURE OF THE ENERGY SECTOR

The Berkeley model includes six different energy sectors: coal, crude petroleum, crude natural gas, petroleum refining, gas utilities, and electric utilities.

Energy Resources

The primary energy sources are coal, petroleum, and gas. In their

preliminary model, Glassey and Benenson depicted petroleum and gas as a single activity in the I-O matrix. In the revised version of the model they split the output of this sector into separate products -- crude petroleum and crude gas -- produced in fixed proportions. This disaggregation of joint products is accomplished by adding two rows to their model to show the sales of oil and gas to other activities. Like the crude petroleum and natural gas sector, coal is represented by a single column in the input-output matrix. The flows of crude oil, crude natural gas, and coal are expressed in energy units (10^{12} BTU). The model contains energy balance constraints so that energy production plus imports equals energy final demand plus industrial use.

Energy Conversion and Distribution

In addition to the three primary energy resources, the model contains three energy conversion and distribution sectors: petroleum refining, gas utilities, and electric utilities. The output of petroleum refining and gas utilities is measured in BTUs; the output of electric utilities in mwhs. Like the primary energy resources, these conversion and distribution sectors satisfy energy balance constraints.

The petroleum refining and gas utilities activities are each portrayed by a single column in the I-O matrix. Glassey and Benenson develop the electric utilities sector in considerably more detail in order to allow for interfuel substitution. The electric utilities submodel contains five generation activities -- coal, oil, gas, nuclear, and hydro -- and a transmission and distribution activity which produces "sold electricity" from "generated electricity." All nonfuel inputs are allo-

cated to the transmission and distribution activity. The generation activities consume only fuel and produce only "generated electricity."

Coal, oil, and gas can be burned in either single fuel plants or in dual-fuel plants (coal-oil, coal-gas, and oil-gas). Glassey and Benenson assume that heat rates depend only on the type of fuel burned, not on the type of plant. Moreover, they assume that all fossil fuel plants are steam plants.

Glassey and Benenson devote most of their efforts to computing the generating capacity constraints on the eight types of plants. To get effective capacity, they estimated installed name-plate capacity and then multiplied by an availability factor. The plant capacity constraints restrict annual output (in mwh). However, because of the substantial fluctuations in electricity demand during the year and the impossibility of "storing" electricity, peak-load constraints must also be added. These two constraints (one for summer and the other for winter) limit total peak power demanded. These peak-power constraints are estimated from a set of linear regression equations.

Prices of Energy Products

No explicit assumptions are made about the prices of energy products. However, the input-output coefficients are based upon pre-embargo energy prices and quantities. Shadow prices are derived for each of the energy constraints.

Interfuel Substitution

Interfuel substitution takes place on the supply side in the electric

utilities sector and on the demand side in the iron and steel production sector.

STRUCTURE OF THE ECONOMY

Level of Aggregation

The economy is portrayed by a ninety-seven-sector input-output table. Five of these sectors are energy related, the other ninety-two represent the rest of the economy. Glassey and Benenson partition these ninety-seven sectors into domestic output and imports. According to them, this separation renders the technical coefficients more accurate and also makes it possible to simulate energy shortages from foreign or domestic trade policy.

Domestic production and imports all face capacity limitations. The upper bound constraints on domestic output are calculated by dividing projected domestic outputs from the Bureau of Labor Statistics by capacity-utilization ratios obtained from the Wharton model. The upper-bound constraints on imports come from a simple scaling upward of base year imports by the ratio of projected imports to base year imports.

Domestic production and imports are all measured in millions of 1972 dollars. The ninety-two non-energy sectors all satisfy the fundamental conservation law of the economy (total dollar value of production plus imports equals total demand). However, the five energy sectors do not, satisfying instead an energy balance. (There is no constraint on the dollar rows of the energy sector.)

The Berkeley model also contains a small employment "submodel." Employment in forty different occupations can be computed for each sector.

However, the only binding constraint in the employment submodel makes total employment less than or equal to the estimated supply of manpower.

In order to incorporate some possibilities for interfuel substitution into the rest of the economy, Glassey and Benenson expand the iron and steel sector. They do so by disaggregating this activity into five different production "processes," with each process differing only by the amount of energy consumed. The five processes correspond to the following objective functions:

- Minimize total costs (energy and non energy)
- Minimize coal use
- Minimize oil use
- Minimize natural gas use
- Minimize use of electrical energy

The coefficients in these processes were derived from a very detailed process analysis (linear programming) model constructed by Missirian (1975). For example, the minimum coal process consists of the energy inputs needed (in the process analysis model) to produce the actual 1972 industry output while minimizing the input of coal. Coefficients for oil, natural gas, and electrical energy processes were calculated in the same way, but with different objective functions (minimal oil use, minimal gas use, etc.). Finally the minimum total cost process simply represents the energy inputs needed to minimize all costs.

Factors of Production and Substitution Possibilities

With the exception of electricity and iron and steel, all outputs are produced in fixed proportions. Moreover, the only substitution possi-

ble in generating electricity and producing iron and steel involve energy inputs. Non-energy inputs are assumed to be identical across all processes in these two sectors.

MACROECONOMIC STRUCTURE

There is no macroeconomic structure to the Berkeley model. Instead, final demand (investment, consumption, government, and exports) are lumped together and determined from outside the model. Glassey and Benenson use the final demand projections for 1978, 1980, and 1985 that are published by the Bureau of Labor Statistics. These projected final demands were first combined into a single final demand vector for each year and then expressed in 1972 dollars by using BLS deflators.

These final demand vectors were then adjusted and used as lower bounds on the final demands generated by the model. Glassey and Benenson (1975a, p. 134) describe this adjustment as follows: "For each sector, a linear regression line was fit to seven data points by least squares, the standard deviation of the residuals calculated, and the final demand lower bound set to the fitted 1972 value less one standard deviation."

GROWTH AND TECHNICAL CHANGE

Since the Berkeley model is a static model, there is no technical change. Growth takes place simply through an upward revision in the constraints on capacities, the labor force, and final demand.

METHOD OF SOLUTION

The Berkeley model is a linear programming model. The objective

function requires the maximization of final demands, which Glassey and Benenson equate with maximizing GNP. The Berkeley model consists of approximately 300 columns and 100 rows. A linear program of this size is considered to be small (see White, 1973) and can be easily solved in a few seconds on many computer systems. The Berkeley modeling group used a linear programming package called GUMPS on a CDC 7600 computer to obtain solutions (see Merrill, Lofting, and Quong (1974) for a brief description of program debugging and testing).

EVALUATION OF MODEL

Capabilities

Glassey and Benenson play the devil's advocate role superbly in a section of their report titled "Limitations of the Model." They divide the model's limitations into the following general categories:

- Those inherent in any linear macroeconomic model
- Those arising from the lack of data
- Those specific to the iron-and-steel and electric utility submodels

A linear input-output model is based upon two assumptions: an economy characterized by perfect competition and equilibrium. As a result, an input-output model cannot be used to describe disequilibrium or the approach to equilibrium. Moreover, examples of market imperfections abound in the U.S. economy, an obvious contradiction of the perfect competition assumption.

The assumption of constant returns to scale also plays a central role in most input-output models. However, as capacity is approached, diminishing returns to scale should be encountered in reality. The energy

sector should also display decreasing returns. Although marginally decreasing returns to scale can be captured in a LP model by including a variety of processes, Glassey and Benenson have opted not to because of the added cost and complexity.

Other limitations encountered in most input-output models and in the Berkeley model include: single-technology production, homogeneous commodities, uniform prices across sectors, L-shaped demand schedules, interdependency of demand schedules, import constraints, regionality, and static analysis.

Single-technology production. In a conventional I/O model, each sector combines various inputs in fixed proportions (the equivalent of a constant recipe or single technology). As a result, no substitution of inputs takes place. In reality, producers often substitute one input for another as prices change.

Homogeneous commodities. The output from any sector is assumed to be homogeneous. In a real economy, a wide variety of products is produced and marketed by each sector. Changes in the output mix may result in changes in the input mix or in capacity limitations which are not reflected in the model.

Uniform prices across sectors. Contrary to the assumption of perfect competition, not all buyers pay the same price for the same commodity. Since output is measured in dollars (for the rest-of-the-economy sector) shifts in demand can distort the model.

L-shaped demand schedules. In the usual LP model the demand function takes an L-shaped form, with demand completely elastic until the lower bound is reached, where it becomes completely inelastic. This causes dis-

continuities to appear in the results and understates the degree of substitution which actually takes place. (Because of the L-shape, no price change occurs as commodities become increasingly "scarce" until the absolute "subsistence" level is reached.)

Interdependency of demand schedules. Complementarity in demand is not reflected in the LP model. This sometimes causes strange results. For example, the Berkeley model shows the hotel sector operating at capacity despite a gasoline shortage. It also shows an increase in activity in the wholesale and retail trade at the same time that the demand for the goods sold by these trades is declining.

Regionality. The Berkeley model is very aggregated, only depicting economic activity at the national level. This is in marked contrast to the distinct regional nature of most energy markets.

Static analysis. The Berkeley model is driven by expansion in capacities. However, there is no assurance that the final vector provides the capital formation needed to achieve this increase in capacity. Also, changes in labor requirements by industry and occupation may be inconsistent with labor mobility (or lack thereof). Finally, no attempt is made to model technological change or energy conservation efforts.

Data limitations. According to Glassey and Benenson (1975a, p. 171), "most of the numbers in the model, and most of the economic structure, come from estimates of transactions flows prepared by the Bureau of Economic Analysis, and these estimates have limitations of their own." First, the underlying flow data are only current to 1967 (although the updating to 1972 appears to perform satisfactorily). Second, the flows are measured in dollars instead of physical units. This reduces the validity of the

fundamental economic conservation equation. Finally, the flow data suffer from the usual statistical discrepancies.

The data used by Glassey and Benenson to develop the iron and steel and electric generation submodels also display a number of shortcomings. Only limited data were available on the iron and steel industry. As a result, prices and input and yield coefficients may not be representative of the industry. Moreover, because of this limited data, iron and steel producing operations were assumed to be completely integrated and centralized. Given the importance of locational considerations to the iron and steel industry, this assumption may seriously distort the results.

In contrast to the iron and steel industry, there is a vast amount of data available on the electric generation industry. But this very abundance of data creates new problems. Indeed, Glassey and Benenson say that the biggest problem in developing this part of the model was in making efficient use of the huge mass of available data. They argue that there is a serious need for a comprehensive, detailed, and consistent data base in a machine readable form.

Uses

Glassey and Benenson perform a valuable service in critiquing their own model. Introspection of this sort is a rare trait in model builders, most of whom apparently feel compelled to sell their findings. Glassey and Benenson also provide detailed documentation of their techniques, analysis, and data sources. For both of these reasons, their report should serve as a "model" to the modeling community.

Even though there is much to learn from the research by Glassey and Benenson, their model still suffers from serious limitations. These

limitations no doubt arise from the severe time constraints (less than one year) imposed on the project, the difficulty of the tasks undertaken, and the multiple objectives of the study.

Glassey and Benenson attempt to do much within the static framework of these models. Indeed, they perhaps attempt to do too much within this framework. Griffin (1976, pp. III-8 to III-9) criticizes the Berkeley model on the following counts:

- One must pause to ask the relevance of 40 labor-type constraints. Surely, during the 1973 embargo, labor was not a binding constraint as the unemployment rate subsequently reached 9%. In addition, labor, unlike energy, exhibits considerable substitution possibilities in the short-run among a variety of occupational groups. Thus the labor supply constraints appear neither relevant for short-run energy supply disruptions nor correctly modelled.

- In principal, introducing short-run inter-fuel substitution possibilities in iron and steel production is a good one. Their implementation appears defective. In deriving the four additional fuel mix vectors, they solve the equivalent problem of minimizing costs where the price of one fuel was "very high" (perhaps approaching infinity). The problem arises in that the resulting solution activity vector, which is entered in the LBL model, does not indicate that such a high price for fuel X is required to obtain that particular fuel mix. Consequently, the shadow price for that particular fuel may be less than that "very high price" required to evince that particular fuel mix and yet it will enter the solution. Thus a peculiar type of non-market clearing behavior is introduced.

- But the most serious objection to this recent work is that the analysis has been used for intermediate and long range forecasting. Fixed I-O coefficients are simply not applicable over such a period for labor requirements coefficients, energy coefficients, etc. In longer run analysis, future shortages which <u>are predictable</u> lead to increased prices for that factor even <u>before</u> the shortage occurs.

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  In sum, we see a useful place for static input-output combined with linear programming, but long run analysis is not one of them.

Anyone planning to use the Berkeley model to study embargoes should also be aware of several other limitations to the model. First, inventories of finished and semifinished goods are omitted and could be of

great importance during an embargo. Second, petroleum products are not disaggregated. Third, final demand is not disaggregated into the important consumption groups. Fourth, the shadow prices of energy products become meaningless in the presence of energy shortages. Glassey and Benenson (1975c) point out that when electricity utility capacity is cut back by 10%, the price of electricity increases by almost 4000%.

The Glassey-Benenson model also underscores the need for specialization in model building. Model building is still in the cottage industry stage with numerous groups all attempting to build their own complete models. But the increasing complexities of models makes it imperative that these inefficient techniques give way to Adam Smith's edict of specialization in production.

For example, the Glassey and Benenson group appears to have spent considerable time in updating and revising an input-output table. This was clearly a duplication of other efforts by groups like CAC and Brookhaven who have already developed elaborate input-output tables.

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