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ABSTRACT

To analyze the application of quantitative models to energy-employment issues, the energy problem was viewed in three distinct, but related, phases: the post-embargo shock effects, the intermediate-term process of adjustment, and the long-run equilibrium. Against this background eighteen existing energy models (government supported as well as private efforts) were reviewed to determine their usefulness in addressing employment problems related to the three phases. The models were divided into three main categories: (1) general-economy energy-sector interactions models, (2) energy sector models, and (3) energy subsector models. Thus far, the models have not been utilized in any significant way for the study of employment and manpower issues. Only one of the category 2 models generates detailed manpower requirements associated with increased investment activity; others in that group as well as several coal sector models could be adapted to do so. Of greatest interest were the category 1 models, but most lack proper price determination mechanism to address long-term questions of adjustment to energy price changes. While most of them incorporate an input-output block to which labor demand estimates are attached, the quality of the specifications was found inadequate. Based on the analysis, five categories of employment and manpower research issues associated with the energy problem were identified: substitution effects, balance-of-payments effects, investment and new construction effects, economic growth and inflation, and distribution of income. (Reviews of each individual model are appended.) (JT)

A REVIEW OF ENERGY MODELS
WITH PARTICULAR REFERENCE TO
EMPLOYMENT AND MANPOWER ANALYSIS

by

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and

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PREFACE

In the course of conducting this review it became increasingly evident that perceptions of the energy problem vary widely. In much of the exposition on models, perception of the energy problem is given only implicitly, in the structure of the model and the simulations performed. In part this is due to the fact that different models address different aspects of a larger set of problems and to the fact that various model builders perceive the problem differently. Hence a useful context for discussing the models and their development includes some attempt at defining the nature and scope of the energy problem. From this vantage point, the heritage of a particular modeling effort becomes more understandable, as does the set of primary employment-energy issues which are likely to be most important over the next decade. Thus, Chapter 1 defines the energy problem and introduces the policy issues which predated much of the modeling effort. Chapter 2 assesses the main employment-energy issues. Against this background, general conclusions from the model review are presented in Chapter 3. Chapter 4 discusses issues that warrant further research and presents recommendations as to further evaluation of models for Departmental purposes. Because of the wide variation in their scope and technical nature and because of the large number of models, individual models are reviewed in detail in Appendix A. These reviews are meant to provide information on what the models are designed to do, their major variables and relationships, and their suitability for addressing problems of employment and manpower analysis. Discussion of the purely technical aspects of the models is kept at a minimum.

The authors were aided by many people in gathering and evaluating

the information on the numerous modeling efforts. In particular we would like to thank Edward Cazalet, Robert Crow, William Finan, Paul Groncki, William Hogan, Edward Hudson, Thomas Joyce, Dale Jorgenson, Dave Knapp, John Kraft, Ron Kutscher and Loren Solnick.

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EXECUTIVE SUMMARY

This report begins by surveying the origins of the energy problem. It notes that the problem, while serious, is not of crisis dimensions. The solution to the energy problem, which is basically a problem of price, lies in making the necessary economic adjustments required when any good or input becomes relatively more expensive. Namely, substitution must occur. It is further noted that the energy problem arose during a time of considerable economic and political turmoil. The monetary "crunch" of 1973, the food price inflation, and Watergate, tended to obscure the perception of the energy problem. The intense effort to do quantitative modeling reflected a widely felt need to fill the knowledge void regarding the degree of interdependence between the general economy and the energy sector, and the need to explore the potential for energy conservation. Initial research was conducted within the government by ERDA, FEA and the NSF. Early private efforts included the Ford Foundation, the Electric Power Research Institute and the MIT Energy Lab. Initial and subsequent modeling efforts and policy discussions have focused little attention on the employment aspects of the energy problem.

The application of quantitative models to energy-employment issues can best be analyzed by viewing the energy problem in three distinct, but related, phases: (1) the post-embargo shock effects, (2) the intermediate-term process of adjustment, and (3) the long-run equilibrium. The post-embargo shock effects, which fortunately are mostly behind us, relate mainly to radically altered expectations, increased uncertainty, and rapid increases in energy prices. The employment impacts during this period were direct (autos, travel, etc.) and readily observable. The second phase, the adjustment process, relates to the manner in which firms and individuals, having perceived fully the permanence of relatively higher energy prices, undertake to make the appropriate substitutions. For consumers this will involve adjustments such as purchasing more energy-efficient cars, retrofitting homes with insulation, geographic shifts, etc. For firms, a similar process of substitution will occur wherein the present energy-intensive capital stock is replaced with one which is relatively less energy-using. These adjustments will not be accomplished quickly or painlessly. The employment adjustments of this period relate to the construction and manufacture of the capital required to implement these new consumption and production patterns. The final phase, the long-run equilibrium, is perhaps the most important in terms of manpower policy. The adjustment phase will create capital stock, consumption and employment patterns that give rise to a mix of skills which will be different than the mix required for the pre-energy problem era. The demands for these skill levels will not be of the transient nature of those required for the adjustment process.

Against this background, we undertook a review of existing energy models to determine their usefulness in addressing employment problems related to the three phases mentioned above. Energy modeling efforts were divided into three main areas: (1) general-economy energy-sector interactions models, (2) energy sector models, and (3) energy subsector models. The first category includes models which treat both energy and non-energy industries in approximately the same level of detail. The purpose of the models is to measure the degree of interdependence between energy industries and the rest of the economy. Most of these models contain disaggregated labor demand relations by sector. They are national in scope with very little regional detail. The second category of models includes those which deal with all of the various energy industries. The main purpose of these models is the study of inter-fuel substitution and the introduction of new energy technologies. These models are generally optimizing (linear programming, etc.), have regional breakdowns, are highly detailed, and are capable of being modified with reasonable ease to study manpower problems. The third category covers energy subsector models (the natural gas industry, coal, electricity demand), world energy models, macroeconomic models and single-equation studies. Among these models, probably the most useful are the coal models, given the present emphasis on coal development in the U.S.

Thus far, the models have not been utilized in any significant way for the study of employment and manpower issues. This situation has stemmed from the predominant interest in questions pertaining to fuel substitution, technology creation, conservation, regulation and legislation, and the effect of higher energy prices on the growth of GNP. The studies dealing with GNP growth showed that higher energy prices, while retarding growth, will not produce disastrous effects. This result is due mainly to the fact that consumers and producers can substitute away from the energy-intensive goods and processes. However, the impact on employment is a much more complex question. Reduced output and slower GNP growth means fewer jobs. However, higher energy prices mean the substitution of labor for energy, which will increase the demand for labor. Which effect is dominant is an extremely difficult and important research issue. Chapter 3 presents general conclusions about the prospects of employing models to study these longer-term issues. A detailed, model-by-model critique is presented in Appendix A.

This survey has led to a few principal conclusions regarding the appropriateness and usefulness of particular models or groups of models for employment and manpower analyses. In the energy sector, which is capital-intensive, the main employment adjustments are likely to prevail only during some intermediate-term period, while the U.S. expands its domestic energy supply sector. The long-run equilibrium labor demand associated with energy output is not likely to be large. Thus, the main employment effects in the energy industry will stem from construction activity and the indirect labor demand associated with increased investment activity. Presently, only the Bechtel ESPM model generates detailed manpower requirements associated with changing patterns of energy sector activity. Other energy sector models, such as the DFI-SRI-Gulf model or any of a number of the coal sector models, such as the Bechtel RESPONS model, could be adapted to generate manpower requirements. The difficulty associated with modifying these models lies primarily in the area of establishing a reliable data base at the highly detailed industry and regional specification level of these models. The fixed coefficient framework of such models would require, at a minimum, that extensive study be made of regional differences in labor productivity. At the present time, it is probably fair to conclude that the activity detail embodied in these models exceeds that warranted by the quality of the data needed to support such detailed specification. Hence, for valid estimates of manpower requirements to be derived from such models, the reliability of both the data bases and the model specifications warrants further testing and development.

Of greatest interest to the manpower analyst are the general-economy energy-sector interactions models. This is particularly true concerning those models which allow for substitution in demand and production as a function of changing patterns of prices. The Hudson-Jorgenson model, in particular, focuses on adjustments within the economy which derive from price-induced behavior. Among the remaining models, only the WEFA annual energy model embodies some form of pricing mechanism in both the demand and production sectors of the model. Other models, such as BLS, Lawrence Berkeley Labs, and INFORUM do not allow for endogenous price determination. This omission may be permissible for some scenarios. However, radical changes in energy prices would not appear to be one. For models other than the Hudson-Jorgenson model and the WEFA model, the lack of a proper price determination mechanism within the structures is also a main deficiency in terms of the ability of the models to address the longer-term questions of adjustment to energy price changes. The models with inadequate specification of pricing behavior are mostly useful for near-term impact analyses, where assumptions about habit formation by consumers and fixity in production technologies are more plausible. In this category of models would be the BLS growth model and the INFORUM model, and the modeling efforts by the Lawrence Berkeley Laboratory.

The Hudson-Jorgenson model focuses on long-run equilibrium values, and largely ignores the short-run adjustment processes. On the other hand, the WEFA model concentrates on these adjustments which arise out of the presence of habit, capital fixity, cyclical behavior and economic inertia in general. With a detailed lag structure, the WEFA model is best equipped to trace out the time path of the intermediate period adjustment process. While most of the energy-economy interactions models incorporate an input-output block to which labor demand estimates are attached, it was found that the quality of the specifications leaves much to be desired. Many of the models determine employment estimates by multiplying average productivity by output determined from the final demands. Effects of prices (i.e. real wage rate effects), substitution of capital for labor, etc., are generally not specified explicitly. Consequently, labor demand is exclusively a function of output in most of these models. Under conditions of smooth growth, in a non-inflationary economy, such a construct might produce plausible results. However, under conditions of rapid cost and price inflation, rapid and substantial changes in energy and materials prices, and hence more significant substitutions in both demand and production, such simple methods for determining labor demand become highly inadequate. In our judgment, a major area for work in adapting present models to the task of exploring employment effects related to energy sector changes is in the area of detailed development of data and empirical estimation of labor demand functions or productivity functions. However, it would be desirable and feasible to utilize the high degree of industry and manpower detail such as is contained in the BLS model. This could be accomplished by using, for example, the output of the Hudson-Jorgenson model which contains far fewer sectors (ten versus 134) as a "control total" for projecting the BLS estimates.

The report concludes with a discussion of the various employment and manpower research issues associated with the energy problem. These issues were divided into four categories: (1) substitution effects, (2) balance-of-payments effects, (3) investment and new construction, (4) economic growth and inflation, and (5) the distribution of income. The substitution effects relate to the types of decisions made by consumers and producers as they face relatively higher energy costs. These problems were outlined briefly above. The balance-of-payments issue arises out of the fact that the U.S. is presently running a substantial deficit as a result of massive oil imports. Continued deficits imply a further devaluation of the dollar in order to correct the deficit. This decline in the dollar has direct consequences for employment and prices in the U.S. economy. The third issue looks at the types of new investment (energy-efficient machines and structures), and exploration which might be expected to occur as a result of higher energy prices. The fourth category examines the relation between higher energy prices and economic growth. Considerable controversy exists over whether or not reduced GNP growth as a result of higher energy prices will reduce or expand employment demand. On the one hand, lower output growth means fewer jobs. On the other hand, higher energy prices mean greater demand for substitute factors such as labor. The last issue relates to the income transfers which will result from higher energy prices and the impact of these transfers on real wages.

Chapter 1

INTRODUCTION AND OVERVIEW

1.1. The Energy Problem. The oil embargo which was in effect from October 1973 to March 1974 imposed a large shock on the economies of the non-Communist world. In a matter of three months, world prices for crude oil escalated to roughly three and one-half times their pre-1973 levels. The oil embargo was the instrument used by the oil-producing and exporting countries (OPEC) to validate the price increases and to solidify their position as the world price leader for crude oil. The embargo and the attendant long lines for gasoline produced the desired shock effect on American consumers. Interestingly, the radically higher energy prices did very little to reduce consumption immediately. It is estimated that the total reduction in oil exports to non-Communist countries during this period amounted to perhaps seven percent of consumption requirements.[1] The actual disruption in physical supply was thus much less important than the impact which came from radically higher prices and the uncertainty generated by the threat of an even more stringent embargo.[2] The embargo, coupled with the gradual depletion of domestic "reserves,"[3] led to the "energy crisis" psychology. The uncertainty generated by this shortage psychology had its greatest impact on the demand for automobiles and related goods and services, such as travel. Occurring

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[1]Fried and Schultze [174], p. 1.

[2]Initially the embargo was intended as a political weapon to shape Mideast policy. Threats of a 25 percent embargo were made, although the final figure was 10 percent.

[3]Domestic production of crude oil peaked in 1971 and "proved reserves" have been gradually declining also.

concurrently with (but somewhat obscured by) the oil embargo, was the monetary "crunch" of 1973-74 which was brought about by a policy directed at containing the 1972-73 price inflation. Sharply higher interest rates and reduced credit availability precipitated a substantial recession in the construction industry and exacerbated the energy-related contraction in auto demand.

As can be seen from Table 1, the employment reductions during the November 1973 to March 1974 period were highly concentrated in these sectors. The combined effect of the oil embargo and monetary policy reduced real GNP growth by two percent for major industrial countries during the first year after imposition of the embargo.[4] For the United States economy, GNP is estimated to have dropped by $10-$20 billion at annual rates during the embargo, and as much as one-third of the rise in the CPI during that period has been attributed to higher oil prices.[5]

Although the employment reductions were substantial and reached their highest level since the 1930's, public attention and governmental policy focused more on the price increases than the unemployment.[6] Three main economic consequences of the anti-inflationary policy merit discussion. First, price controls for crude oil and natural gas were instituted and subsequently extended. Since import prices were not controlled, this led to a two-tier pricing system, with consumer prices determined by the rela-

[4]Fried and Schultze [174], pp. 18-21.

[5]See Perry [194], pp. 96-97.

[6]Back-of-the-envelope calculations on the respective costs of inflation versus unemployment are $65.0 billion in lost jobs versus $165.0 billion in cost-of-living losses. The public was "inflation conscious" at this time, having just gone through the food price inflation period. Also, "Watergate" was diverting considerable public attention.

Table 1

Employment Changes During the Embargo, 1973-74*

Industry, Sector	Total Employment (000) November 1973	March 1974	October 1977	Change (000)	Percent. Change November 1973 to March 1974
Total Nonagricultural	78,728	77,442	82,926	-1,286	-1.7
Private Nonagricultural	64,627	63,162		-1,465	-2.3
Construction	4,194	3,762	3,940	-432	-10.3
Manufacturing	20,480	19,987	19,632	-432	-2.4
Durables	12,147	11,847	11,561	-300	-2.5
Motor Vehicles & Parts(SIC 371)	766	625		-142	-18.5
Nondurables	8,333	8,140	8,077	-193	-2.3
Trade	17,188	16,564	18,429	-624	-3.6
Wholesale	4,205	4,162	4,409	-43	-1.0
Retail	12,983	12,402	14,020	-581	-4.5
Auto dealers & service station	1,810	1,628		-183	-10.1
Eating & drinking places	3,098	3,052		-47	-1.5
Finance, Insurance & Real Estate	4,133	4,167	4,564	+34	+0.8
Services	13,275	13,345	15,523	+70	+0.5
Government	14,101	14,894	15,368	+793	+5.6

*Source: U.S. Department of Labor, Employment and Earnings, United States, 1909-75. November was chosen as the first month to fully reflect the impact of the embargo.

tive amount of domestic versus foreign crude supply.[7] Second, as a combined result of long lags in supply response, increased costs, environmental restrictions, price controls and uncertain government policy, domestic production continued the decline begun in the mid-1960's. Hence, over the past three years the U.S. has continued to import more crude oil and as a result has incurred increasing balance-of-payments deficits. Third, prices and wages,

[7] So-called "new" domestic crude is exempt from price controls.

particularly in the non-competitive sectors of the U.S. economy, were escalated in response to increased energy costs.[8] Higher wage rates were passed on in the form of higher prices in the private sector, and contributed to inflationary budget deficits in the public sector.[9] These escalations produced a general inflation which over time reduced the nominal rise in gasoline prices from 68 percent to a relative rise of 30 percent. The net effect of "generalizing" the particular energy price increases was to reduce the incentives to conserve on energy.

1.2. Energy Policy and Quantitative Modeling. As noted above, the public perception of the energy problem was colored by the events of time. Furthermore, as a result of these events and other commodity shortages, the government was not prepared to analyze this new-found problem.[10] Although some experts had warned of the consequences of continued price controls on natural gas, the slowdown in domestic exploration, and the heavy dependence on Mideast oil, little if anything had been done in the way of analyzing the industrial impact of an oil embargo and/or radically higher oil prices. Hence, policymakers were at a genuine loss in terms of their ability to understand the dimensions of the problem. The lack of an organized basis for making judgments and asking relevant questions was recognized and steps were

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[8] See Hall [179] on market structure and wage behavior. Kosters [186] has also analyzed the effects of increased coverage of cost-of-living adjustments in raising overall wage-push inflation during this time period. His study suggests that higher wage sectors were better protected against real wage erosion.

[9] Similar increases were granted recipients of transfer payments, particularly social security beneficiaries who received a "double dip" in 1976 due to a technical error.

[10] For an analysis of these other shortages, see NCSS [191].

taken to rectify this intelligence void. One of these steps was the initiation of energy modeling efforts.

One of the main purposes of any economic model is to organize information. At a very basic level this may be nothing more than asking which variables are supply factors and which are demand factors. On a more sophisticated level it may give detailed information on prices, output, employment, wages and capital for hundreds of sectors of the economy. Hence models, inter alia, provided a means for describing the dimensions, assessing the magnitude and ramifications of the problem, as well as performing the analytical tasks of measuring the feasibility and impacts of various conservation programs on the demand side and various technology adaptation and development policies on the supply side. Support for and interest in quantitative modeling of the energy problem came from two main sources--the Federal government (through the Federal Energy Administration, the Energy Research and Development Administration, and the National Science Foundation) and private organizations, especially the Ford Foundation and the Electric Power Research Institute. A good deal of the impetus to government-sponsored research arose out of the Project Independence mandate for energy self-sufficiency. Strong emphasis was placed on the development of alternative technologies, especially nuclear.[11] This type of outlook was more in the nature of planning for new technologies and meeting specified energy requirements given various institutional and economic constraints, as opposed to simulating the impact of various energy programs or policies. The planning-type efforts tended to center on optimization or linear programming models.

[11] Originally ERDA was composed of a conglomeration of energy-related agencies. The most dominant by far of these agencies was the Atomic Energy Commission.

One example of this approach is the work done at the Brookhaven National Laboratory (BNL) on the Brookhaven Energy System Optimization Model (BESOM).[12] The BESOM-model incorporates detailed engineering information for a variety of new, as well as existing, energy technologies. The BNL recently, for example, conducted an analysis using the following four submodels: (1) the Data Resources Inc. (DRI) macroeconomic growth model, (2) the DRI inter-industry energy model, (3) the BNL-University of Illinois (U of I) input-output model, and (4) BESOM. These various models were linked in order to study the energy and economic impact of a wide range of government energy policies.[13] While policy at ERDA emphasized the technological-type models, the government's other energy arm, the FEA, was more concerned with the economic adjustments actually taking place. Although many models were developed at FEA, the main one used for policy planning and forecasting is the Project Independence Evaluation System (PIES) model. The PIES is a fully integrated model which includes sectors for commercial and residential energy demand, transportation, refineries, utilities, coal, gas and oil supply, and international trade. Since the FEA was the agency responsible for supply allocation administration during the embargo (and would have presumably been the agency in charge of rationing should it have been deemed necessary), this type of model is appropriate for their purposes.

Concern over the interactions between the general economy and the energy sector has not been lacking. In particular, the Ford Foundation, through its Energy Policy Project (EPP), was among the leaders in perceiving this aspect of the energy problem. In a report to the EPP in September of

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[12] All BNL work is sponsored by ERDA (now DOE).

[13] See Behling [3].

1973,[14] Professor Dale Jorgenson and Edward Hudson presented an interindustry transactions model for use in analyzing energy-general economy interactions. This model, in conjunction with the DRI long-term growth model, was used by Jorgenson and Hudson to analyze the impact on prices and output of the proposed BTU and excise tax under consideration by the Congress. This model was then further used by Jorgenson and Hudson to analyze three separate economic growth scenarios (historical, technical fix and zero growth) which were a major input into the EPP final report, A Time to Choose.[15] The model has been used in many other applications including the interindustry sector of the BNL model. One of the most important features of the model is that it gives direct measures of the degree of substitutability between the various factor inputs.

Another institution in the forefront of energy research is the Electric Power Research Institute (EPRI), which is supported by the electric utilities industry. One large-scale effort supported by EPRI is the Wharton Econometric Forecasting Associates (WEFA) energy model. The WEFA energy model combines econometrically estimated demand relations for 67 categories of final demand with a 63-sector interindustry model. As such the model portrays the economy in great detail, especially the energy-producing and using sectors, and is very useful in studying the interactions between the general economy and the energy sectors. Developed in 1976, the WEFA energy model is fully operational and was used recently to simulate the effects of the crude oil equalization tax.[16] The EPRI, along with supporting research in other energy-related areas,

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[14] Houthakker and Jorgenson [182].

[15] Freeman [170].

[16] Schink and Finan [196].

is also developing an in-house energy subsector model. In addition to the above activities the EPRI also provides support to the Energy Modeling Forum (EMF) of the Institute for Energy Studies, Stanford University. The EMF provides a forum for interested parties from academia, government (congressional and administrative), and private industry to meet and formulate energy policy and research issues. As a first effort, the EMF has conducted an assessment and comparison of six major energy-sector general-economy models.[17] Additional work was also carried on at Stanford University in the Engineering-Economic Systems and Operations Research Department under sponsorship of the Office of Naval Research (ONR), ERDA and NSF.[18] Additional university-supported energy research is conducted at MIT's Energy Lab.[19]

The above overview is not intended to be all-inclusive with respect to individuals and institutions involved in energy modeling. Such a detailed review of modeling efforts is the purpose of Appendix A. The purpose, rather, is to convey the main impact of government policy on energy modeling.[20] More importantly, it hopes to show how and why certain models were developed and how modeling entered the policy process. The large number and wide diversity of energy models reflects the wide divergence of perceptions of the energy problem and attendant policy issues or priorities to be addressed. In industry, government, and academia, the use of models tends to be related to the type of responsibility or activity in which the decision-making unit is

[17]See EMF [19].

[18]See Dantzig and Parikh [16], Dantzig [15], and Parikh [35].

[19]See Berndt and Wood [133], Berndt and Wood [134].

[20]The converse, the impact of modeling on government policy is not dealt with here. For a treatment of this interesting topic, see Greenberger, Crenson and Crissy [176].

involved. For example, within the Federal government, such interests encompass a wide range including the following sorts of issues:

- economic disruption and national security
- exploration and development of alternative energy sources
- conservation techniques
- macroeconomic policy adjustments, price level and balance-of-payments effects
- long-term economic growth and employment effects

Each particular model structure incorporates specific advantages and limitations with respect to particular applications. Hence, it is important for the decisionmaker to be able to choose a model which is appropriate for assessing the particular issues with which he has to deal, while at the same time being fully aware of what is not included in the model and technique. In reviewing and assessing existing energy models with a view toward their applicability for studying problems of labor demand, two central questions must be borne in mind. First, what are the energy-employment issues? Second, are the models capable of addressing these issues? Before going into the detailed assessment of the models, it is desirable to give focus to that assessment by reviewing the energy-employment issues. The following chapter is devoted to that task.

Chapter 2

EMPLOYMENT-ENERGY ISSUES OVER THE NEXT DECADE

In assessing the employment-energy issues it is useful to do so in a manner which attempts to project a changing economic environment, at least as it relates to energy problems. This changing economic environment may be characterized in three distinct but interrelated phases. The first phase is the initial shock, which produces substantial reductions in GNP, double-digit inflation, and huge income transfers to the energy-producing sectors. This phase is of interest because its effects still persist to some degree and because, conceivably, it could be repeated. The second phase, which is the adjustment process, is in the early stages. This phase is characterized by reductions in energy consumption by consumers and producers in response to higher prices, the initiation of new technologies such as solar heating, exploration for new energy sources such as the Alaskan north slope or the North Sea gas fields, energy-saving investments, and government policies designed to facilitate the transition and give economic relief to those who are adversely affected. The third phase relates to the equilibrium values for economic variables such as prices, employment and output once all the adjustments are complete. This is not meant to imply that the economy will eventually end up in a static equilibrium, but rather that the adjustments to higher energy costs will be completed and a new economic-energy morphology will have emerged. This configuration will have manpower-skill requirements which are conceivably quite different from those which exist today.

2.1. Post-Embargo Shock Effects. As recounted above, the oil embargo created considerable economic uncertainty, the main direct effect of which was to reduce the demand for autos and travel. The other main direct employment effect was in housing where demand was curtailed more by the "credit crunch" than energy-related actions. A good deal of the economic distress usually identified with the energy crisis can be ascribed to the inflationary conditions prevailing in 1972-73 and the consequent restrictive monetary policy. There is no doubt, however, that the oil embargo and its aftereffects intensified recessionary pressures, added substantially to the inflation already under way, and had disastrous effects for the balance-of-payments. Nonetheless, it is difficult to foresee even with the help of hindsight what policy options might have been taken to avert the problems. Should an embargo be reimposed, even under more stable economic and social conditions, the effects could well be the same, mitigated perhaps by petroleum stocks and the experience of having "muddled through" the first embargo. Valuable lessons were, of course, learned from this period. However, the main consequences relate to how events during this period set the stage for the second phase--the adjustment process. The employment impacts during this period were immediate, obvious, and as such did not require any particularly sophisticated modeling effort to analyze them.

2.2. Sustained Higher Relative Prices for Energy--The Adjustment Process. The main consequence of the formation of OPEC appears to be permanently higher energy prices. While the authors do not share the view that the world is fast running out of fossil fuel,[21] it does appear true that most

[21] Or for that matter, that the U.S. is running out. On this point, see Houthakker [125], pp. 13-17. While it is not the purpose of this report to detail the history of commodity shortages in the U.S., an historical perspective is useful in assessing some of the positions taken and claims made with respect to fuel "reserves" and prospects for discovering new sources. The U.S. first experienced a petroleum shortage in 1917 when the Director of the

of the "readily accessible" (hence economical) fuels have been discovered. This means that OPEC's final price will be equal to the cost of bringing out the marginal barrel of new crude, which is likely to be quite high, providing OPEC countries with substantial economic rents.

Adjustments to permanently higher energy prices can be expected in three main areas. First, relatively higher prices will create incentives for consumers and producers to conserve on energy-intensive items. For consumption patterns, this will mean more fuel-efficient cars, electrical appliances, and homes, for example. Retrofitting existing homes through better insulation, storm windows, or partial solar heating are other options. If markets are "freed up," and most indications are that eventually they will be, then relative prices will rise in proportion to the energy-intensiveness of the product. Although consumers may not make the kind of "fine line" adjustment to price differentials often portrayed in economic texts, a definite tendency to conserve will be present. The impact on employment is, however, difficult to assess. As consumers turn away from energy-intensive products, they will substitute other products whose labor requirements may be such as to raise <u>net</u> employment. Most basic energy products--i.e. gasoline, electricity, natural

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Bureau of Mines recommended that oil shale would soon become the country's main source of petroleum, because of the shortage of oil fields. (U.S. Dept. of the Interior, Bureau of Mines, <u>Seventh Annual Report</u>, 1917, p. 78). This statement was followed by a study in 1919 which concluded that petroleum reserves in the U.S. were 40 percent exhausted (<u>Engineering and Mining Journal</u>, October 4, 1919, p. 572). In 1924, then President Calvin Coolidge established the Oil Conservation Board. The Board's conclusions issued in 1926 were even more startling—only six years left. This prediction was followed by two decades of oil gluts, during which time not even the most gullible of the citizenry would support any more scarcity scares. However, by 1944 the Congress had succeeded in passing the Synthetic Liquid Fuels Act which included substantial funds for the BOM for research on synthetic fuels. Again the rationale for the passage of this act was the alleged shortage of petroleum, which according to the testimony would be "of the most serious proportions by 1950" (<u>Synthetic Liquid Fuels</u>, Hearings before the Subcommittee of the Senate gas--have very low labor requirements. Furthermore, labor in these industries is more of an overhead item, in that employment is not proportionate to output. Hence, a 20 percent reduction in refinery output would not be likely to induce a 20 percent employment reduction at the refinery. When assessing consumer substitution possibilities, the outlook for generating additional labor demand is quite good, especially with regard to home insulation and solar heating.[22] On the other hand, the production of energy-efficient cars may be accompanied by continued trends toward labor-saving technologies. The real danger to employment here is the threat from foreign imports. If foreign carmakers do have a technological advantage over the U.S. (a conjecture which we doubt) in the production of fuel-efficient cars, then employment in the auto industry could suffer considerably, leaving aside exchange rate effects, and foreign direct investment in U.S. production of foreign makes.

The other major aspect of the substitution question is the extent and direction of incentives for producers to substitute labor for energy as a result of higher energy costs.[23] In an input-output analysis for three separate time periods during the postwar period, Reardon [44] found that energy use varied greatly between periods in response to demand shifts and technolo-

Interior and Insular Affairs Committee, January 29, 1948, p. 27). These "shortages" have not been confined merely to petroleum. For accounts of shortages in general see Bruce Netschert, Shortage, Scarcity and Doomsday Fears (National Economic Planning Associates). Various Presidential Commissions have been established to deal with commodity shortages. These have included the President's Material Policy Commission (1951), popularly called the Paley Commission, the National Commission on Materials Policy and most recently, the National Commission on Supplies and Shortages. See Government and the Nations Resources (Report of the National Commission on Supplies and Shortages, December 1976).

[22]See Ziegler [202], pp. 21-24 for a description of the CETA-sponsored Solar Technician Program at Sonoma State College.

[23]See Berndt and Wood [134].

gical changes. In production, energy efficiency gains, even prior to the 1970's were substantial, though these were offset by shifts in demand (more autos, air travel, chemicals and plastics, electrical appliances and services tended to raise overall energy consumption requirements over time). If, as some initial studies have shown, capital and energy are complements and both are substitutes for labor, then it is likely that the high energy prices will bode well for labor demand. This very point has stirred considerable controversy,[24] both with respect to the validity of the complementary relation between energy and capital and, more importantly, whether or not energy impacts will be output and hence labor-reducing. The argument turns on whether the amount of reduced output will be greater or less than the demand generated by the substitution of labor for energy. Professor Jorgenson has advocated the position that higher energy prices will expand the demand for labor (the substitution effect will dominate), while others such as Professors Domar, Bischoff, and Asimakopulos have taken the opposite position (the output effect will dominate). Clearly, the energy-producing sectors such as refineries and electric utilities will attempt to substitute labor and capital for energy. Unfortunately, direct substitution effects will probably favor capital and not labor, as employment is very small in these capital-intensive sectors. Hence, even substantial percentage increases will not be a great source of new jobs. The indirect effects on employment generated by increased capital expenditures may be the more significant response here.

The second main way in which permanently higher energy prices will affect the demand for labor is through their effect on the general level of prices. The U.S. economy has already experienced a great deal of price in-

[24]*Business Week*, September 12, 1977, pp. 134-138.

flation as a result of the energy price increases. This inflation has had adverse effects on investment and hence economic growth and employment. Inflation tends to raise interest rates by an amount reflecting a price expectations premium. Higher interest rates tend to reduce investment in general and construction sector activity in particular. Inflation also increases the replacement costs of existing capital goods rendering reserves from depreciation based on historical costs inadequate to meet replacement requirements. It also increases (in conjunction with higher interest rates and higher capital goods prices) the user cost of capital, which reduces the incentive to invest. Perhaps most importantly, inflation reduces investment because of the <u>uncertainty</u> which it generates. Investments require considerable planning and generally are spread out over time--plans must be drawn, contracts let, equipment purchased, labor hired, etc. If businessmen cannot know with some reasonable degree of certainty what prices they must pay at these future times (or what price they will receive for their product), risks associated with investment can become prohibitive. Higher inflation rates push both individuals and corporations into higher tax brackets. In combination with understatement of depreciation charges, this tends to shift resources from the private to the public sector, which if not offset by appropriate tax reductions tends to reduce incentives to produce. Finally, inflation removes the differentials between energy-intensive goods and other non-energy-intensive goods which, in turn, reduces the incentives to conserve on the scarcer resource--energy.

The third effect of higher energy prices on employment is through the balance-of-payments and exchange rate mechanism. For reasons mentioned earlier the U.S., since the lifting of the oil embargo, has steadily imported more crude oil and more natural gas. This increased importation at prices three and a half to four times their pre-embargo levels has led to massive U.S. trade deficits and contributed to the weakness of the dollar in foreign exchange markets. Continued devaluation of the dollar will imply that the U.S. must devote more and more of its resources to the export sector, which implies an overall reduction in living standards for U.S. citizens. Since many other nations, both industrial and less developed, are also running trade deficits, the final outcome of this international realignment is extremely difficult to analyze. For example, while a net devaluation of the dollar might lead to higher exports, the higher prices for imported goods would contribute to domestic inflation, and the net employment effect of the devaluation might well be negative, as recent experience seems to show. Much of the longer-term outcome depends on what the OPEC countries do with their petro-dollar surpluses. If they import goods for consumption, or lend funds to other deficit countries, the U.S. will probably benefit. If they invest in U.S. and foreign businesses and "live off" the interest, then the effect will be quite different.

2.3. <u>Long-Run Energy Developments--The New Equilibrium</u>. Once adjustments to the four-fold increase in energy prices have occurred, the economy will, in the absence of other disruptions (which presumably will occur), take on a new set of equilibrium values. The term equilibrium does not imply that there will be, for example, no growth. Rather, it simply means that a new growth rate (a new set of balances between supply and demand) will be established. More importantly, as related to energy, it means that the new technologies such as solar heating, nuclear or geothermal electricity generation, new insulation standards and, most importantly, ideas and innovations not yet conceived, will be nearing their long-run market shares. The U.S.

economy will be somewhat more labor and capital-intensive, somewhat less energy-intensive. With regard to labor demand, there are two aspects of this new equilibrium which are of interest. First, there are the industry particular effects such as what will be the employment-skill configuration in the solar heating industry. It is these industry-specific effects which will be of great interest to manpower analysts. The second aspect deals with the configuration of the general economy as it relates to the increased scarcity of energy. General industry and trade will, as a result of higher energy prices, require a different skill mix in the labor force as a result of the adjustment.

Assessing the manpower requirements and labor demand configurations which will occur as a result of economic changes implied by each of the three adjustment phases mentioned above is indeed an ambitious task. In a manner similar to the way in which they were employed to analyze the initial energy issues (mainly conservation), models can make a contribution to understanding the issues outlined above. The earlier objectives for energy models were to provide a "map" of the terrain and to determine the extent and feasibility of conservation measures. This type of analysis, while difficult, did not involve conflicting goals. However, the analysis of the employment impacts of conservation policies or, for that matter, price controls, will indicate trade-offs between the two. Indicating trade-offs is one of the main functions of economic analysis. In doing this analysis, models will, of course, be useful. However, such analysis will also prompt a closer scrutiny of the models and their results.

Chapter 3

GENERAL CONCLUSIONS FROM THE MODEL REVIEW

The purpose of this section is to provide analytic summaries of the various types of energy models, to categorize the various models according to the types of problems which they can address, and to assess the capability and adaptability of these existing models for the study of employment and manpower problems. The models are categorized by three main subdivisions. First are the general-economy energy-sector interactions models. These models attempt to portray how, and to what extent, the general economy depends on the various energy sectors and vice-versa. These models are typically highly disaggregated in order to show differential effects on various non-energy sectors. Next, the review focuses on the large energy sector models. These models encompass all of the various energy types and/or sectors, but do not contain non-energy sectors. Lastly, we look at individual energy sector models, such as natural gas, electricity, etc.[25]

3.1. General-Economy Energy-Sector Interactions Models. Models included under this heading are those which generally portray both the energy economy and the rest of the economy and allow for feedback both ways. For example, these models are capable of analyzing the effect of a crude oil price increase on employment in the machine-tool industry as well as its effect on energy-related industries. Hence, the main purpose of these models is to analyze the prices of primary energy inputs. In fact, these models were built primarily to analyze the impact on GNP growth of restricted energy supplies. Models of

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[25] Detailed reviews of individual energy models are given in Appendix A.

this type can be conveniently divided into two distinct, but sometimes overlapping groups. The first group includes models whose relations are specified on the basis of economic theory, whose solution technique is simultaneous and whose principal architect is trained in economics. This group is referred to as simultaneous models. The second group of models relies on relations based on engineering data and known physical processes. These models use optimization techniques, such as linear programming, to arrive at the solution and are frequently designed by engineers, mathematicians and individuals with training in operations research. These models are referred to as optimization models. As such they tend to downplay the role of demand and price vis-à-vis the simultaneous models. By the same token, the simultaneous models tend to ignore the detail of alternative engineering processes and detailed supply considerations. Ideally--i.e. if both types of models were correctly specified--they would yield identical results. Such, however, is not the case. The optimization models, because of their detail and because of the ease with which physical constraints such as environmental regulations can be adapted into the models, are perhaps more useful as planning devices. This is not a trivial consideration since large parts of the energy economy are presently planned through considerable government regulation. On the other hand, the simultaneous models portray more of a "free market" solution and frequently lack the detail necessary to model particular restrictions and regulations. Another important difference is that in the simultaneous model, relations based on economic theory assume maximization by individual micro units--e.g. consumers maximize utility, producers maximize profits. However, the optimization models employ aggregate objective functions, such as the maximization of gross national product, etc.

The simultaneous models include the Hudson-Jorgenson model, the WEFA energy model, the Kennedy-Neimeyer model, the BLS growth model, the Hnyilicza model, and the INFORUM model. These models are centered around an inter-industry transactions model, varying in size from two industries in Hnyilicza to 185 in INFORUM. They are typically "driven" by a set of econometrically estimated final demands for consumption, investment, exports and (exogenous) government. These final demands are converted from expenditure categories to interindustry (SIC) classifications by bridge matrices. The interindustry sector is then used to determine total output by industry, labor demand by industry, imports, etc. Next, prices and wages are determined, either behaviorally or via I-O accounting identities. Given wage rates and employment (plus other components) income can be determined and the model is closed, since income is the main driving force in the final demand vector mentioned above. The interindustry sector in these models is handled in a manner which allows the I-O coefficients to respond to price change (Hudson-Jorgenson and WEFA) or which are modified in some judgmental or structural method (BLS and INFORUM). The energy sectors represented in these models are portrayed in the same level of detail as the non-energy sectors. As a result, the degree of industry-specific knowledge or detail contained in these models for any given industry is quite low. This is not unexpected, nor for that matter undesirable. Depiction of each energy industry in detail in a model which also contains the general economy in some detail would lead to models which are unmanageable in size and incomprehensible for analytic purposes. All of the above-mentioned models contain labor demand relations for each of the industries within the model. The BLS model has the added feature of determining manpower requirements by industry by skill group. The other models could be easily modified to incorporate this feature since they also determine industry employment.

The simultaneous models typically assume full employment. This is done either by letting population (which is exogenous) determine the labor force and then setting the unemployment rate at, say, four percent and computing labor demand or by adjusting government employment. Labor demand can then be fed into the aggregate production function along with other inputs to yield total output. At first it may seem quite contradictory that the models assume full employment. There are perhaps two reasons why this is done. First, economic theory has no real explanation for unemployment in a growth-oriented potential output model. Neoclassical economic theory assures full employment of all factors through assumption of competition in factor markets, i.e. factor prices will adjust until full employment is reached for each factor. The Keynesian model shows how to create sufficient aggregate demand to meet some given historical potential output level. However, the Keynesian model ignores the crucial issues of growth and supply of output, thus making its usefulness limited. The second reason is a more practical one. As projections are made further and further into the future the errors from each equation become successively larger. A two percent error in the labor demand equation coupled with a two percent error in the opposite direction in the labor supply relation will produce a 100 percent error in the unemployment rate. Hence, long-run projections can, quite easily, produce forecasts for the unemployment rate which are prima facie suspect. This can be remedied by changing labor force and/or labor demand estimates, or (as is more likely) by fixing the unemployment rate at some predetermined level. In this sense the unemployment rate is a control variable. The same can be accomplished on the capital side by setting the rate of interest exogenously.

Among the models mentioned above, the Hudson-Jorgenson is perhaps best suited to study problems of long-run equilibrium. The Hudson-Jorgenson model, as noted in the Appendix, ignores lags and habit formation in consumer and producer behavior. Also, the estimates of the model reveal considerable flexibility in terms of price responsiveness. Given institutional, technological, psychological and financial rigidities present in the U.S. economy today, this degree of flexibility is to be expected only in the long run after full adjustments have occurred. However, the manner in which the I-O coefficients are determined (i.e. from relations estimated from time series data) is superior for long-run analysis to the judgmental approach of BLS and INFORUM.[26] The H-J model is composed of two main submodels. The first submodel is a nine-sector interindustry transactions model with four general economy sectors and five energy sectors.[27] The energy sectors are coal mining, crude oil and gas, refining, electric utilities, and gas utilities. The main function of the interindustry model is to determine prices, I-O coefficients and, hence, interindustry flows and industry employment. The other submodel, a macro econometric model, determines total employment, output, consumption, investment, the wage rate, price of capital services, capital stock, wealth and leisure time. The two key relations in the macro model are the production possibility frontier and the household consumption-leisure utility function. The former yields the investment supply, consumption supply and labor demand, while the latter yields consumption demand, leisure time demand and, implicitly, savings. The production possibility frontier relates labor and capital inputs to outputs of consumption and in-

[26] The WEFA model also employs price-sensitive I-O coefficients.

[27] The nine-sector aggregation level is based on the model described in Jorgenson and Hudson [26]. This model was modified to include eighteen sectors, fourteen of which are energy, for DRI in March 1977. See Dullien, Hudson and Jorgenson [18] for a description of the DRI long-term interindustry transactions model. See also Appendix A for a further description.

vestment goods. The labor demand relation is derived from this frontier and displays unitary elasticity with respect to the wage rate, price of capital services, and quantity of capital services. Investment supply is expressed as a transcendental function which has no closed form representation. Hence, the elasticities cannot be computed. Ignoring the transcendental term, the supply elasticities for investment with respect to the price of investment goods, price of capital services and capital service flows are all unitary also. Through the use of multiperiod utility function, present and future consumption are linked via the interest rate and the subjective discount rate. Hence, increases in the interest rate should affect leisure demand, consumption demand and hence savings. However, although the slope coefficient for income in the consumption demand relation should be a function of the interest rate,[28] it is treated as a constant.[29] Furthermore, the individual demand relations for consumption and investment for each sector have unitary price and income elasticity and zero cross-price elasticities. Because of the assumption of constant returns to scale, all individual industry supply curves have zero supply-price elasticity, i.e. they are perfectly flat. However, since the model is a general equilibrium model, the operational properties of individual relations when the whole model is solved simultaneously may be quite different. An interesting exercise for the H-J model would be to compute the reduced form multipliers and multipliers for selected endogenous variables to gain a better understanding of the operational characteristics of the model. Despite the shortcomings mentioned above, the Hudson-Jorgenson model

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[28] See Dullien, Hudson and Jorgenson [18], pp. 12-13.

[29] See Dullien, Hudson and Jorgenson [18], p. 13 and Jorgenson and Hudson [26], p. 487.

is an impressive accomplishment. It is the first internally consistent, fully simultaneous empirical model of economic growth. It is based on a solid theoretical foundation and is implemented with a system of accounts, designed by Jorgenson, which are compatible with growth concepts (mainly flows of capital services) used in the model. The model is not overburdened with detail, but is presented in sufficient depth to delineate the major sectors of the U.S. economy. Also, the model overcomes an important data limitation of interindustry models. Interindustry flows and totals are available only for a few selected years. Hence, a time series is unavailable for estimation of total output production functions by industry. The use of the translog price frontier allows the model to capture interindustry cost relations in a satisfactory manner and, at the same time, impose none of the restrictions implied by the lack of availability of output data.[30]

As was noted above, the H-J model is strictly an equilibrium model. No attempt has been made to build in the lags and adjustment processes which must accompany the movement from one equilibrium point (or path) to another. A model perhaps better suited to study these shorter run adjustment problems is the WEFA energy model. The WEFA energy model consists mainly of a Keynesian-type system for the final demand block, a price-sensitive interindustry

[30]The analysis of the Hudson-Jorgenson model presented above is based on the model as described in Jorgenson and Hudson [26], Jorgenson and Hudson [27] and Jorgenson [184]. Since the time of these publications considerable changes have been made in the model. Many of these changes were in response to criticisms of the type given above. The model presently contains ten sectors instead of the nine listed above. The crude petroleum and natural gas sector has been disaggregated into two separate sectors. The macro model no longer contains a production possibility frontier, but now relies on the production relations (price frontier dual) of the interindustry model. The demand relations have been generalized to include cross-price effects and the unitary elasticity assumption for own-price and income have been replaced by estimated values.

transactions model, and a wage-price block built on "Phillips curve" and key industry wage relations and price equations based on wages and I-O prices. The WEFA model is based on annual data. The various demand relations were estimated using the Almon lag technique. These lags imply lengthy adjustments, some extending back seven years. The price-sensitive I-O coefficients display a geometric adjustment process over time.

However, in comparison with Hudson-Jorgenson, the WEFA energy model has important differences. These basic differences reduce primarily to the fact that the WEFA energy model, while containing important extensions, remains basically a Keynesian model. This is revealed by the limited role which the interindustry sector actually plays in the model. Given wage rates, implicit value-added deflators are determined by unit labor and capital costs and rates of change of value-added output. Next, interindustry prices (WPI's) are determined by the value-added price for that sector and the (I-O weighted) other interindustry sector prices. The final demand prices are then related to the WPI prices through the use of the I-O final demand bridge matrix. However, although total industry outputs and interindustry flows are computed in the model, their only use appears to be in the computation of the I-O coefficients to compute the WPI's. Labor demand in manhours by industry is a function of value-added (not total) output by industry and industry capital stock. This is referred to as an inverted production function approach. If so, the sign on the capital stock variable is often incorrect. Also, this specification fails to distinguish between the level of capital stock and the flow of services from the stock. More important is the exclusion of all intermediate and primary factors (except labor and capital) from the labor demand relation.[31] Exclusion of these inputs has implications for the production function which are clearly unrealistic.[32] Also, this implies that changes in energy costs affect labor demand only indirectly, i.e. through demand-induced changes due to changes in relative prices. A similar critique can also be made of the investment demand relations. Furthermore, another fundamental question arises concerning the lack of use of the interindustry sector. This question centers on the supply or offer curve for each industry. Given prices and income, output (both value-added and total) is determined. Hence, the supply relations, as in the H-J model, are buried in the price formation relations. However, the H-J model explicitly assumes constant returns to scale and hence flat supply curves. Close examination of the WEFA value-added price equations reveals that they imply supply curves with both increasing and decreasing returns to scale. However, as specified, the price equations are not intended to reflect the degree of returns to scale. Rather the specification is based on the short-run relationship between prices, unit costs and profit margins. Furthermore, such factors as differential trends in unit costs and prices by industry due to data errors will be absorbed as returns to scale phenomena. Such is not possible in a growth model with a fully integrated set of accounts. Also the ties between present and future consumption and production of investment and consumption goods are not as specific as in the H-J model. For example, no aggregate consumption function exists in the WEFA model. Hence, ties between future and present consumption occur mainly via the effect of the interest rate on durable demand, an effect

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[31]The other primary factors are raw materials including crude oil, natural gas, coal, etc. For a further discussion of the inclusion of raw materials in a production function context, see Eckstein and Heien [164].

[32]See Berndt and Christensen [156] and Denny and Fuss [162].

which has more to do with financing arrangements than present-future consumption trade-offs.

The above critique is not meant to imply that the WEFA energy model is not useful in addressing questions of energy policy as it relates to labor demand. The degree of industry detail is very useful, especially for manpower analysis. More important is the treatment of lags and adjustment processes. The WEFA energy model is the only general-economy energy-sector model to deal with these adjustment processes in a meaningful manner. Furthermore, the WEFA model does not require the assumption of full employment, making it even more useful for the shorter-run adjustment question. Even for longer-term analyses this may be important since, as noted in Chapter 2, the issue of whether higher energy prices produce a larger substitution effect or output effect is still not fully answered by present research efforts. The interactions of differential lags structures, especially on the demand side, should reveal interesting characteristics of the adjustment path for output, prices and employment. However, the labor demand relations should be reworked before any such analysis is undertaken.

The remaining general-economy energy-sector simultaneous models which are of interest are the INFORUM model by Clopper Almon at the University of Maryland and the Bureau of Labor Statistics (BLS) economic growth model. Although containing important differences, the BLS and INFORUM models are quite similar in structure and operation. Both models rely on an I-O matrix driven by a vector of final demands. Furthermore, both models share common shortcomings such as lack of market adjustment processes, lack of price behavior, lack of financial sectors and financial links, ad hoc adjustment procedures, especially with regard to input-output coefficients, and inadequate labor demand relations. At present both BLS and INFORUM lack price determination equations of any kind. In INFORUM, prices are exogenous[33] while in the BLS model only aggregate consumption goods prices are determined via a Phillips curve relationship in order to determine real disposable income which drives the consumption functions. Prices apparently have been removed from the consumer and investment demand relations, so relative price adjustments are not modeled. Basically, there is no price behavior in the BLS model. Without endogenous price behavior, no real adjustment between supply and demand occurs within these models. There are no supply relations, not even existing implicitly as price equations. In the INFORUM model, consumer and investment demand does depend on prices. However, since the prices are exogenous, demand is supply, as in the BLS model. Furthermore, since there is no price behavior, the effects of wages on costs and prices is non-existent. By the same token, interest charges play no role in the model as there is no financial sector to link savings, investment, and the money supply to interest rates. Both models rely on non-economic mechanisms for the adjustment of I-O coefficients. In the INFORUM model I-O coefficients are adjusted on the basis of logistic curves, estimated with historical data, and ad hoc judgment. Either way, the behavior is not price-induced as economic theory would suggest. BLS also uses ad hoc adjustment of the I-O coefficients, although work on a price-responsive system is under way. For long-run projections of an economy under assumptions of a relatively unchanging structure (or continuation of past trends), such adjustment procedures may be adequate. However, for simulations of the effects of a major change, such as energy prices, employing this procedure will lead to erroneous projections. Of particular weakness in these models is the treatment of labor demand. Labor demand (L)

[33] Future versions of INFORUM will have a full price determination sector.

by industry is arrived at by multiplying labor productivity (L/Q) by Q where Q is the (previously arrived at) industry output. However, the estimate of labor productivity is made independent of wages, prices and output. This implies, inter alia, that the elasticity of labor demand with respect to output is unity, a highly implausible assumption. More importantly, it excludes from labor demand the important effects of changes in wage rates, other input costs, output prices, and technological change--all of which have been found to be important determinants of labor demand in practically every successful empirical study of the subject. Reservations notwithstanding, these models can play a role in energy-employment analysis if used in the proper manner. The level of detail, 185 sectors in INFORUM and 134 sectors in the BLS model, and the incorporation of employment projections by occupational category in the BLS model, makes these models quite appealing for manpower analysis. Also, the BLS model has the advantage of Bureau-wide expertise in productivity, employment, wages and prices. The models could be used within bounds prescribed by the results of analytically more rigorous models, such as Hudson-Jorgenson or WEFA. It would be possible to take total and sectoral output and prices from various runs of the H-J model and use them as input assumptions (control totals) in the BLS or INFORUM models. However, before any such exercise is undertaken, the labor demand relations should be reworked.

The second group of models in the general-economy energy-sector interactions group includes those models which use explicit optimization techniques as their basic methodology. These models include the ETA-MACRO model (Energy Technology Assessment), the PILOT model, some of the work at Brookhaven National Laboratory with the BESOM model, and work at the Lawrence

Berkeley Laboratory.[34] Although it contains only one non-energy industry, the ETA model uses non-linear optimization techniques to choose among sixteen energy processes. Constraints on savings, investment, labor, and output come from the macro model while energy outputs are determined by the ETA optimization model. The PILOT and LBL (Lawrence Berkeley Lab) models are structured somewhat the same, utilizing highly detailed process models of the energy industries and input-output representations for the non-energy sectors. Unfortunately, the suppression of price behavior and the use of fixed I-O coefficients (as process coefficients) in PILOT and LBL effectively reduces the scope for economic choice to the point where these models cease to be attractive as instruments of analysis for economy-wide scenarios. This group of models is characterized by disaggregation of the production side. Typically, the models incorporate both an interindustry structure and a detailed energy sector. This detail reflects recognition of the extensive substitution possibilities which exist among both primary energy forms, and means for power conversion. In addition, this structure permits modification of energy and other production technologies in the way of allowing for introduction of new energy supplies and technologies. More fundamentally, it reflects a recognition that energy is a derived demand, and that its immediate importance is to the supply potential of the economy. Hence, the focus is on detail for the supply side of the economy in the modeling structure.

Among this class of models (general-economy energy-sector interaction optimization models), ETA-MACRO and BNL portray the economy with sufficient realism to warrant use as manpower forecasting tools. Even then there are

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[34]In Appendix A the BESOM and Lawrence Berkeley models are included in the section on energy sector models. This was done because although the non-energy sectors are represented, their role in these models is minor.

serious drawbacks. ETA-MACRO has only one good produced for final demand. Hence, output is generated from the supply side by the mix of inputs--electric energy, non-electric energy, full employment labor, and capital. The model could be substantially improved by providing for the output of two goods--one energy-intensive, one not. Then price-sensitive demand relations could be added to capture the differential demand effects as energy costs (and hence prices) rise over time. As presently constituted, output is more like a "control variable" which tracks the model out over long periods of time, rather than a summation of individual industry outputs. Hence, the model can address questions of employment and occupational demand only within the energy sector where, as has been noted previously, employment is not large anyway. However, the model does represent a varied array of alternative energy technologies[35] and use of the model will yield growth patterns for each of these various technologies (such as are found in the Bechtel energy supply planning model), construction manpower requirements associated with various energy scenarios could be analyzed. Hence, ETA-MACRO is useful for simulation of long-run energy sector developments with some interactions with the general economy. In order to add realism to the model, additional work, indicated above, needs to be done on the general-economy (MACRO) sector.

The other optimization model which shows promise for general-economy energy-sector interaction analysis is the Brookhaven energy supply optimiza-

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[35]Those various technologies include: for electricity—hydro, fossil, low-cost coal, high-cost coal, light water reactors (LWR) no plutonium recycle, LWR plutonium recycle, fast breeder reactors, and advanced solar electric; for non-electric—petroleum and natural gas, coal-based synfuels, shale oil, electrolytic hydrogen, low-cost non-electric alternative ($5/mil. BTU), high-cost non-electric alternative ($8/mil. BTU), and coal (other than synfuels).

tion model (BESOM)[36] linked to the Hudson-Jorgenson DRI interindustry growth and macro models. This configuration uses the H-J DRI models for the non-energy sectors and links the BESOM linear programming and BNL-University of Illinois I-O models to them. These links are not simultaneous, hence the models are iterated back and forth until certain consistency checks are met.[37] BESOM contains more technological detail than ETA-MACRO. For example, synthetic fuels, one category in ETA, is divided into coal synfuel and oil synfuel. Also, environmental and regulatory constraints are included in BESOM. The model is fully adaptable for the study of manpower analysis and projections, and contains considerably more non-energy industry detail (110 I-O sectors) than does ETA-MACRO. However, the size, the degree of detail, and the lack of documentation tend to make the model almost incomprehensible.[38] Nevertheless, it is a useful tool, especially for energy-sector analysis where some interaction with the general economy is required but is not the primary focus.

Recently, the Energy Modeling Forum (EMF) completed a comparative analysis of the major general-economy energy-sector interactions models.[39]

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[36]In some versions referred to as Dynamic Energy Supply Optimization Model (DESOM).

[37]See Appendix A for a further description of the linking procedure.

[38]In reviewing the model, Professor Lave expressed a similar sentiment, "This size, complexity, and wedding of models leaves me slightly uneasy; I cannot find precisely what assumptions or structure of the model produces the results observed in the scenario." Hitch [22], p. 285. As noted in the Appendix, lack of proper documentation plagues all of the models reviewed and BNL should not be singled out. This lack may have resulted from the time pressure under which much of the work was done.

[39]See EMF [19]. The Energy Modeling Forum, directed by Professor Hogan at Stanford, is administered by the Institute for Energy Studies, Stanford University, and sponsored by the Electric Power Research Institute. The Forum is composed of individuals from industry, business, government and universities who share common interests in energy modeling.

Included in this analysis were the WEFA, H-J, BESOM-H-J-DRI, PILOT, Kennedy-Neimeyer and Hnyilicza models. The comparison was based mainly on operational characteristics of the models, i.e. by comparing actual model outputs from runs made under a common set of assumptions. Such an undertaking is quite formidable and the EMF is to be commended for accomplishing such a task. The main results of the comparison are worth quoting in full:

> "In the presence of constant energy prices, increases in economic activity produce similar increases in energy demands, although these may be moderated by trends toward less energy intensive products and services.
>
> But higher energy prices or reduced energy utilization need not produce proportional reductions in aggregate economic output. There is a potential for substituting capital and labor for energy and the contribution of energy to the economy, relative to these factors, is small.
>
> The models do show some significant reductions in economic output resulting from higher energy prices. The magnitudes of these reductions are very sensitive to the substitution assumptions implicit in the models. Further, the impacts may be large for individual sectors of the economy.
>
> The benefits of energy substitution may be lost in part if energy scarcity impedes capital formation. Reduced energy inputs may cause lower levels of investment and, consequently, reduce potential GNP. This indirect impact may be the most important effect of energy scarcity." 40

The following shortcomings were also observed:

> "All the models examined focus on the long run potential of the economy. Abrupt changes in energy availability or other policies with short term implications may affect the realization of this potential GNP, but are not within the scope of the models studied here.
>
> The models require assumptions about future population or labor force growth and the rate of technological change, which other things equal, determine the growth path of the GNP. The analysis here is directed at the changes in growth due to changes in the relative scarcity of energy, not to absolute levels of future economic activity.

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[40] EMF [19], p. iii.

> The representation of nonmarket behavior is difficult to include in the models. The effects of regulation, industrial organization, or the expectations created by government's future role are not well understood.
>
> The models treat environmental considerations in a rudimentary way. They do not address the causes and effects of persistent unemployment nor the impacts of unexpected embargoes. Financial sectors are highly stylized or absent in many of the models. Such important issues require different analytical approaches or major model extensions." [41]

In addition to the above comments, various empirical measures were extracted from the models' performance characteristics. All of the models showed approximately the same relation between output expansion and changes in energy demand, at constant energy prices.[42] The results indicate approximately a 6.7 percent increase in energy use for each 10 percent increase in real GNP. However, important differences do exist with respect to the elasticity of substitution (σ) between energy and other inputs. Also, for some models σ varies over time, becoming greater in the long run. The short and long-run values for σ are given in Table 2. The figures in Table 2

Table 2

Short and Long-Run Values of the Elasticity of Substitution for Various Energy Models

Model	Short-Run	Long-Run
PILOT	.03	.03
Kennedy-Neimeyer	.06	.06
WEFA	.10	.20
Hudson-Jorgenson	.30	.54
Hnyilicza	.37	.38
BESOM-H-J-DRI,	.28	.58

[41] EMF [19], p. iv.

[42] Energy use for the same GNP level was somewhat higher (20%) in PILOT and Kennedy-Neimeyer.

verify the earlier observations regarding price-induced changes in the I-O coefficients in H-J, WEFA, and BESOM-H-J-DRI, as well as the price-induced demand effects in these models. These figures also reveal the fixed price, fixed I-O coefficient nature of PILOT. The almost doubling of the elasticity in the long run (here about 25 years), in H-J, WEFA, and BESOM, reveals that habit and adjustment play a role in these models. The change in the WEFA model is due to the lags discussed earlier. In the H-J model it is probably due to the translog price frontier which allows σ to be a variable depending on the price level. In either case, the realism of the model is enhanced.

All of the models considered in detail here are capable of studying problems of labor demand and manpower projections and analysis. However, most models, with the exception of BLS, would have to be modified with a manpower requirements estimator, as is used in the BLS model. All of these models estimate employment by industry and, with the exception of H-J, all have considerable industry detail. In application, these models assume full employment. As indicated above, this is a virtual requirement of long-run growth models. Hence, analysis of labor demand should center around average hours worked, real wage rates, and the occupational and interindustry shifts which occur as a result of energy policies and prices. None of the models in this category deals with regional effects.[43] Demographic and regional shifts will play an important role in the future and their importance must not be minimized. However, if these models attempted to deal with regional effects, they would most likely be unmanageable. The models considered in the next section include regional effects.

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[43]The WEFA model does contain an eight-region electric utility submodel based on Griffin's pseudo-data model. See Griffin [138].

3.2. Energy Sector Models. Models included in this category are those which encompass all of the energy industries but which do not portray the non-energy industries. Included in this group are the BESOM (BNL) model, the DFI-SRI-Gulf model, the FEA-PIES model, the Bechtel ESPM, and the LBL (Lawrence Berkeley Laboratory) model. The energy sector models have two distinct advantages over the models discussed in the previous section. First, they are regional in orientation, which is a crucial aspect of many energy research issues. Second, the models portray the individual energy industries in much greater detail. Within this group the BESOM model, the LBL model, and the supply side of the PIES model are linear programming models. The demand side of PIES, which is econometrically estimated, and the DFI-SRI-Gulf model are simultaneous supply and demand models. The parameters for the relations in the DFI-SRI-Gulf model are obtained from technical experts in energy industries. The Bechtel ESPM is an accounting-type model which, given final energy demands by region, determines requirements for 75 categories of capital, manpower, materials and equipment. The model does determine in considerable detail the manpower requirements needed to construct energy extraction and conversion facilities. The LBL model also contains relations for detailed manpower requirements (adapted from the BLS model). The other models could be modified to do so.

The practical difficulties in modifying most of these models to incorporate estimates of manpower requirements revolve around data problems associated with obtaining independent information regarding productivity and labor costs on a region-specific and activity-specific basis. Typically, for a given plant or facility (technology), such models assume costs to be homogeneous nationwide, which ignores differing wage rate and productivity behavior by region and by plant. In addition, to properly estimate future wage rates and thus labor demands, regional labor supply would have to be estimated. If this is not done, labor requirements estimated by multiplying average labor-output requirements by outputs generated by the models will exclude important elements of economic behavior. Ignoring regional impacts of wage rates on labor demand would be plausible only if wages were set equal by a nationwide collective bargaining agreement, or if the elasticity of demand for labor were insignificant. However, in the energy sector, particularly in activities such as the drilling of oil and gas wells, or in the construction of facilities, wage rates are known to differ significantly by region and even within region. Hence, to properly augment these regional energy sector models, regional labor market models would have to be developed, a formidable task given data limitations, but one that merits further research.

As noted above, the energy sector is capital-intensive. This, in fact, is the central point to the energy sector employment analysis. Human energy (labor) and animal energy have, in industrialized societies, been replaced by fossil fuel and nuclear energy. This is particularly true in electricity generation and crude oil refining, and to a lesser extent in coal mining and oil and gas drilling and transmission. Hence, the main direct demand for labor at this level will arise from construction and equipment requirements for new refineries, new electric generation plants, new oil and gas wells, etc. Thus, the long-run equilibrium demand for labor in energy-related industries is likely to be quite small. The main long-run problem relates to the effect on the demand for labor (and the skill mix required) in non-energy-producing industries, i.e. to what extent will labor be substitutable for energy as energy prices rise relative to labor.

Within the energy-producing sector, the question of government regulation and energy legislation becomes relevant. Environmental restrictions, conservation policies, price controls, fear of even greater price controls, government inertia with regard to leasing public land for exploration, and the myriad of other governmental regulations surrounding the coal, electricity and natural gas industries are the main inhibiting factors retarding construction in these industries. Process-type models such as those reviewed in this section are reasonably well suited to modeling restrictions of the type referred to above. However, in order to incorporate new construction activity and the subsequent labor demands, most models require some reworking and augmentation.

The principal energy-sector models are all of the optimization or process variety. It is argued that this is an advantage in evaluating the impact of energy price or supply changes which lie outside the range of historical experience as would be captured by an econometric model. Optimization or process models always "solve", so-to-speak, no matter what values are inserted for the parameters (such as demand elasticities), and in this sense are a flexible tool for simulation purposes. However, this same flexibility carries with it some important drawbacks. First, such models are typically not oriented so that economists can readily understand and evaluate them. For example, basic measures such as elasticities of demand and supply are implicitly buried in the engineering structure and must be extracted through simulations--an exercise which, in most cases, has not been carried out. Second, models such as these are based on engineering data which related to processes. It is difficult to link this type of data to national economic data, particularly for employment purposes. Third, the models, once the constraints are specified, concentrate on minimizing the cost of specified energy demands. Ignoring lags, inertia, and interactions with other economic conditions, and being non-stochastic, such models present <u>no</u> information on the statistical precision with which the estimates are known. Furthermore, the results are quite sensitive to price assumptions. Quite large shifts from one technology to another are observed as a result of small cost changes.[44] Most importantly, the results are quite sensitive to the estimates of the supply curves. These estimates are, however, quite arbitrary. Hence, the models display an imbalance--minute optimization on the one hand, arbitrary parameters on the other. In addition, although solution of these models conceptually represents optimal, long-run equilibrium resource choice where relative prices and relative marginal products are equated, in practical operation, errors made in estimating various technical or cost variables may negate the value of being able to "optimize" in terms of model solution. A useful test for such models would be to assess how well they determine a historical data point, or how well they can "backcast."[45] As it stands, we do not have any real information on the sensitivity of various components of such models to error, or the sensitivity of particular solutions to changes in particular variables or parameters.

Among the models reviewed, the Bechtel ESPM and DFI-SRI-Gulf models are most amenable to being modified for estimation of manpower requirements. In fact, the Bechtel model already generates detailed manpower requirements, but the model is weak from a behavioral point of view. It appears that some of the data in the Bechtel model could be utilized in the DFI-SRI-Gulf model (as there is already some data commonality between these models), and perhaps unit manpower requirements can be derived for remaining activities in this

[44]See Lave in Hitch [22], p. 298.

[45]A useful exercise for these models would be to test their prediction accuracy, either <u>ex-ante</u> or <u>ex post</u>. Experience with what appears to be perfectly plausible optimization models in agricultural economics has led to wholly unacceptable predictions.

model not included in the ESPM. However, as noted above, if technical and cost information is limited to national averages, without modification for regional differences, the regional aspect of the output will not be of great accuracy. In addition, augmenting the models with simple labor-output relationships will not be a substitute for a more complete labor market model which would assure consistency between the labor demands and the costs which enter into the technology choices presently derived by these models.

3.3. Energy Subsector Models. Models reviewed under this heading are those which pertain to a particular energy industry. Coverage includes the coal industry, natural gas, electricity demand, gasoline and automobile demand, world energy models, single-equation studies and, for the sake of completeness, conventional macroeconometric models. Much of what was said in the preceding section applies here also with perhaps the only drawback being that most of these models do not capture interindustry substitution effects between competing fuels. As before, the long-run equilibrium labor demand for these industries is small relative to the potential employment demand associated with building new facilities. Comments pertaining to modification of energy sector models to allow for determination of labor requirements apply equally to the subsector models. The regional detail of the larger coal, natural gas and electricity demand models imposes the same need to further develop and complete a regional data base including wage rates, productivity estimates, and information on manpower availability. Particularly for the coal industry, deriving reliable point estimates of average productivity over longer time horizons will be a challenging task confronting the manpower analyst. Among the difficulties encountered in estimating future productivity trends in the coal industry will be the effects of technological changes, shifts from deep mining to strip mining, and the effect of government-mandated health and safety rules and workmen's compensation and health insurance programs. To a lesser extent, parallel problems in measuring future productivity will be encountered in electricity production as a result of regional output shifts, technological shifts (to nuclear generation or to more coal-fired, steam-generating plants), and health and safety regulations. The present, very imprecise analysis of facility, regional and national trends in productivity in these sectors will necessarily make any estimates of manpower requirements based on output and average productivity estimates very tentative. Detailed skill requirements will be even more subject to doubt, particularly for points further out in time. Consequently, for existing models to be adapted in a meaningful way to produce manpower projections in the energy sector and sub-sectors, for longer-term analyses, considerable work will be required to develop reliable information about likely productivity trends.

Despite reservations such as those noted above, some initial attempts at modifying these models would appear feasible. For example, if the regional data base for the Bechtel coal model could be expanded to include manpower data such as contained in their ESPM model, then some of the implications of national energy and environmental policies could be assessed in terms of employment requirements. Thus far, there has not been a great deal of interest in evaluating the employment and manpower effects of policies which would affect regional coal production (or aggregate coal output), as the concern has focused on the implications of emissions standards on regional output, transportation and capital requirements. Similarly, the MacAvoy-Pindyck natural gas model, which is regional, could be modified to generate employment demands associated with new drilling and investment activities corresponding to various market prices for natural gas. The same sort of reworking of the Baughman-Joskow electricity demand model is possible. Given government policies with respect to price setting, environmental standards, etc., employment effects accompanying adjustments on the supply side of the industry could be derived from the model, if the requisite regional data base can be developed. Other electricity demand models, having less specification of the supply side of the industry, are less amenable to use for manpower analyses. In this category are models like the Oak Ridge National Laboratory. For models of this type to be utilized, they would have to be tied to a more comprehensive model or set of models (such as BESOM or PIES), and this sort of effort is in fact presently underway, though not with an emphasis on deriving manpower estimates.

Demand models for gasoline, like most of those for electricity demand, are ill-equipped for use in the study of employment. However, the demand for autos, which is dependent on gasoline prices, does have substantial employment effects. The question of the effect on durable goods of higher energy prices has received little attention thus far despite its relevance for the employment question. The macro models, to the extent that there is sufficient detail can, of course, provide some answers to this question. However, more detailed analysis is needed. The macro models have been more usefully adapted to analyzing short-run impacts of demand reductions, such as accompanied the oil embargo and its aftermath. Most of these types of simulations have been performed and the results are reasonably well known. World economic models, such as Project LINK, could conceivably be used to examine the employment-related questions of a continued balance-of-payments problem by the U.S. The problem of a steadily falling dollar due to oil imports is immense and has so many facets that it is perhaps too much to ask one model to analyze. This is particularly true in view of the fact that there is virtually no historical experience to indicate which industries will be affected and what various ramifications might be expected. Nonetheless, the LINK, or similar multi-country models, are prime candidates for use, as well as domestic macro models, especially for estimation of the immediate impacts.

The one remaining area which has been touched on above is that of regional or locational analysis. As discussed above, the energy problem will prompt relocation of industries, workers and consumers--each for reasons of their own. The move to the Sun Belt, by both industry and individuals, will no doubt be accelerated by the higher energy prices, as well as the changing demographics of the U.S. population. The energy sector and energy subsector models are regional and can be used to analyze this phenomenon for those industries. However, for the macro economy, regional-disaggregation makes for models of unwieldy size.[46] The most important gap in this area is analysis for non-energy industries of regional location and migration, for it is from these non-energy industries that the greatest impacts will be felt. Some work has already begun in this area by Sandoval and Schnapp [150], Sandoval and McHugh [149], Huntington and Smith [147], and Solnick [151].

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[46]For an attempt at this combination, see Donnelly et al [143] and Donnelly and Hopkins [144].

Chapter 4

EMPLOYMENT-ENERGY RESEARCH ISSUES

As discussed in Chapter 1, the initial modeling efforts were aimed at assessing the possibilities for energy conservation and/or new technologies, and were particularly aimed at analyzing the interaction between the energy sector and the general economy. The question of most importance was the effect of higher energy prices on economic growth. With the passage of time and the benefit of reflection, it is becoming increasingly clear that higher energy prices and the policies adopted have substantial consequences for employment and job creation. However, these consequences have not been fully explored, with the result that U.S. energy policy is still a void with respect to the employment issue. This chapter hopes to illuminate what these issues are and how the models surveyed above might or might not assist in their evaluation. The employment-energy issues may be divided into five broad categories: (1) substitution, (2) balance-of-payments, (3) exploration and investment, (4) relation between energy prices, economic growth and employment, and (5) the distribution of income.

The substitution question has two main aspects--substitution by consumers and substitution by producers. As energy prices rise relative to other prices, consumers will buy less of the energy-using or energy-intensive products. In products or services where direct consumer purchases of energy are involved, such as for autos and utilities services, more immediate sorts of adjustments should be expected. For example, heating of homes with electricity is presently a relatively expensive method due to the technical inefficiency of electric heating in this application. Depending on how various fuel prices change, consumers may respond by switching to gas or solar heat, insulating, wearing warmer clothes indoors, turning down thermostats, or even moving to more moderate climates, or some combination of the above. This substitution process may take some time, as habit, technological and financial constraints must be overcome. The degree of response to price which can be expected will depend in large measure on the permanence of changes in relative prices of various consumption goods and services. In the longer run, the kinds of adjustments will reflect direct and indirect effects of energy prices and energy policies. For example, higher prices of primary energy inputs used by electric utilities to generate power can be expected to be passed through to consumers of electricity. If regulatory policies also change the pricing of electricity according to marginal cost of service, such institutional changes will produce further price effects. Similarly, until natural gas pricing methods become fully visible to consumers, choices among alternative sorts of household appliances and their utilization rates remains problematic. For consumer products where consumption of the basic item, such as the automobile, requires joint purchase of other commodities or services (gasoline, insurance, etc.), final adjustment to direct and indirect energy-related price effects can be expected to involve a complex set of interactions. If the magnitude of the direct and indirect price effects is significant over the longer run, substantial employment effects can be expected as a result of increased demand for less energy-intensive (and hence more labor- or capital-intensive) goods and services. While it is true[47] that less will be purchased of the relatively more expensive good, it is not clear that more will be purchased of other competing goods. This, in the jargon of the demand analyst,

[47] According to the conventional economic theory of consumer behavior.

depends on whether the income effect outweighs the substitution effect. However, on balance, one might expect that these substitution effects away from energy-intensive products and services would tend to expand employment.

In the production sector of the economy, similar substitution processes prevail, but with probably even more variety than in the consumer sector, as habit is perhaps less binding and the variety of sectoral differences in substitution possibilities may be greater. Although, ability to adjust capital stocks or organizational methods imposes similar constraints in the short run. Thus, in the energy sector, changes in basic input prices will alter fuel choices for producing, say, electricity. In the longer run, technological substitutions, new methods for pricing energy products, etc., will be derived and applied. In other parts of the production sector, where various goods are produced, forces for substitution will derive from both final product market responses (consumer demand adjustments, for example) and from changes in input prices. Direct responses to higher energy input prices are likely to result in only modest adjustments in the production structure due to the short-run fixity of the capital stock. Over the longer run, however, producers can be expected to revise the configuration of inputs and outputs in response to more permanent price signals. The <u>exact</u> manner in which this substitution process is likely to occur is difficult to predict. An important aspect of adjustments by producers, for example, stems not from prices <u>per se</u>, but rather from the certainty (or uncertainty) with which expectations about prices and other variables can be held. A good deal of this aspect of the path of substitutions revolves around responses to actual or expected government policies. For example, uncertainty over the availability of physical supply of energy inputs, such as natural gas, may induce producers to relocate in Sun Belt states if there are also other reasons to do so. The final interface between supply and demand will result in a new configuration of final product demands and input requirements (capital, labor, energy, raw materials, and intermediate products). Resulting long-run adjustments will remain to be measured empirically, but, in general, it will be true that an increase in the price of an input (or a decrease in its availability) will result in increased use of substitute inputs.[48]

A final sector to be included in any study of the effects of higher energy prices on employment is the government sector, which is a major consumer of energy. In the past, the rapid growth of state and local government construction activity, as for building highways and schools, has produced extensive growth in demands for energy. At the federal level, a defense establishment based on conventional means of warfare has been relatively energy-consuming, at least in terms of fossil fuels. In the future, military hardware relying on nuclear power, rocket fuels, etc., to a greater extent than in the past will alter the mix and level of fuel requirements. State and local government activities shifting away from highway and school construction and toward other forms of services more appropriate to an aging population will also imply significant substitutions.

While models will not be well-suited to the study of detailed substitutions which will no doubt take place as energy prices change relative to other prices, some of the basic, broad patterns of input and output substitutions which can be expected in the longer run can be studied using some of the general-economy energy-sector interaction models (such as the Hudson-Jorgenson

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[48]This depends, to some extent, on whether or not labor, capital, energy and materials are substitutes or complements. For recent empirical work on this subject, see Berndt and Wood [134], and Hogan and Manne [140].

model).[49] From such analyses, broad trends in sector shifts in employment and manpower demands can be studied.

The second major area of research interest is with respect to the effects of energy prices and imports on the U.S. balance-of-payments, and the resulting feedback effects on domestic output, income, employment and price level. Presently, this country is running a substantial trade deficit, in considerable part related directly to energy imports, and also because export demands are being moderated by the slow growth of other economies. The growth of the world economy is itself very much a function of world oil price effects on price levels, output levels and balance-of-payments deficits. Domestic energy policies (price controls, entitlements programs, etc.) have not induced expansion of domestic supplies or restrained consumption, but have contributed to the rise in energy imports to cover domestic demands. Failure to reconcile domestic energy pricing policies with realities of the world energy market has contributed to the devaluation of the dollar against stronger currencies of some Western European countries and Japan. To the extent that a large trade deficit-cum-devaluation continues or recurs, further cost pressures are imposed on the U.S. economy, particularly if world oil producers are able to implement increases in the dollar-dominated world oil price, as the dollar devalues against other major currenci Resultant higher domestic inflation rates and interest rates coming from this source engenders "fiscal drag" on the economy through the tax system, and dampens investment (particularly interest rate-sensitive construction sector activity), and otherwise makes management of domestic monetary policy difficult. Offsetting output and

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[49] The above discussion intentionally abstracted from the employment and manpower aspects of the new investment undertaken as a result of these changed patterns of supply. This subject is dealt with below.

employment reductions from interest rate-inflation rate effects of devaluations and rising dollar oil prices are theoretically positive effects on demands for domestic outputs for sectors that face import competition--steel, autos, textiles, shoes, tourism, etc. Net employment effects from adjustments in such industries will depend on whether net export price elasticities of demand are greater or less than domestic and foreign income elasticities of demand for the products and services in question. Given the way in which higher import prices affect costs, and the way in which domestic industries adjust prices in response to reduced import competition, the basic question to be asked here is whether or not the job preservation and creation aspects of a falling exchange rate will offset the real income decline which will accompany it.

For the longer run, terms-of-trade developments between the U.S. and oil-exporting countries will raise questions about the size and nature of real resource transfers. Petro dollars not used for purchases of U.S. exports will take the form of real and financial investments. Investments in the U.S. will earn interest, earnings which if converted to stronger currencies will put sustained pressure on the dollar. Given uncertainties about future trade and payments positions of other major industrial countries, determination of the impact of petro-dollar investment flows on income growth and stabilization in industrial economies has become a complex issue. Studies are underway at the Federal Reserve Board, employing trade and financial flows models, to determine some possible outcomes of changing petro-dollar flows on industrial economies, but many questions here remain unanswered.

A third set of issues involves investment responses in the economy (both energy and non-energy sectors) which can be expected to accompany substitutions away from energy-intensive consumption and production. In the energy sector, the production of new energy sources such as nuclear, geothermal and solar power, etc., will entail new construction and new equipment. Continued exploration for conventional fuel sources such as oil and gas, as well as their extraction, will require skilled manpower resources in unprecedented numbers. Coal mining, while highly capital-intensive, requires equipment, the production of which does require considerable manpower. It is perhaps in this area that the potential for manpower analysis is the greatest. Models such as the Bechtel ESPM can be modified (work is currently underway) to incorporate detailed labor requirements categories for energy plant construction activities. Various energy scenarios could be outlined as a function of different assumptions concerning energy policy and developments, and evaluated with either general-economy energy-sector interactions models or from energy sector models.

Research in this area could perhaps be conveniently divided into three areas. First would be the manpower requirements from increased exploration and development of new and existing energy supplies. Second would be the construction of new electricity generation plants and gas or oil transmission pipelines, i.e. conversion and transmission facilities. Third would be the new plant and equipment in the non-energy sector which would be constructed in response to new capital needs determined by substitution effects. An important aspect of this research would be to assess the effects of governmental regulation, especially on new exploration and construction of power plants (particularly nuclear). Environmental restrictions, land-use planning and zoning, Interior Department policy regarding private exploration on public lands, etc., all figure prominently in decisions to build new plants or otherwise commit capital.[50] Also figuring prominently, particularly for non-energy industries, is the question of relocating to areas where energy (and other) costs are lower. Analysis of locational responses also applies to new home construction, as homeowners relocate to more energy-efficient areas.

The final area of possible research is the effect of energy prices on economic growth. Some initial work by Jorgenson [26] and EMF [19] has already been accomplished in this area. However, further research is warranted, particularly concerning the relationship between growth and employment. Studies tend to indicate that the general economy and the energy sector can be "decoupled" to the extent the growth is not substantially slowed. Furthermore, the relation between growth, employment, inflation, the distribution of income, and balance-of-payments should be examined in a systematic interrelated manner.

An issue in the area of applied empirical and econometric research connected with the growth, employment and substitution questions will be that of developing more detailed and more reliable labor demand functions, or productivity estimates. In this review, it was found that productivity estimates (from which most employment estimates are derived) associated with input-output models, or models such as the Bechtel ESPM, are very weak estimates and not based upon adequate data or econometric methods. Consequently, for the state-of-the-art to advance in developing employment estimates from detailed energy-economy or energy sector models, considerable further work will have to be devoted to developing labor demand and productivity concepts and measurement.

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[50] Due to environmental restrictions, no new electric generating plants have been constructed in California during the past eight years. Total elapsed time from lease acquisition to geothermal power generation in California is six to nine years. (See Santa Rosa Press Democrat, Dec. 27, 1977).

Appendix A

DETAILED REVIEW OF THE MODELS

A.1. General-Economy Energy-Sector Interactions Models. The models surveyed in this section are those which portray both the general economy and the energy sectors. Furthermore, the energy and non-energy sectors are linked together so that feedback effects, both ways, are captured. These models are the most general of all the energy modeling efforts, are typically quite large, and utilize econometric or interindustry approaches (often both) as opposed to optimization techniques. The models reviewed under this heading include: (1) the Hudson-Jorgenson model developed by Dr. Edward Hudson and Professor Dale Jorgenson for Data Resources Inc. (DRI) under a contract with the Ford Foundation Energy Policy Project; (2) the Wharton Economic Forecasting Associates (WEFA) energy model, which is an enlargement of the WEFA annual model and was sponsored by the Electric Power Research Institute; (3) the BLS growth model which has been adapted to study energy problems; (4) the energy technology assessment (ETA)-MACRO model developed by Alan Manne at Stanford; (5) the INFORUM model developed by Clopper Almon at the University of Maryland which, like the BLS model, has been adapted to study energy problems; and (6) other general-economy energy-sector interactions models.

A.1.1. The Hudson-Jorgenson Model. This model, which has been used extensively to analyze energy policy issues, has as its core a nine-sector interindustry transactions submodel. This submodel contains the following:

[1]The model was first described in Chapter 5 of Houthakker and Jorgenson [182]. Later studies included Jorgenson and Hudson [26] and Jorgenson and Hudson [27].

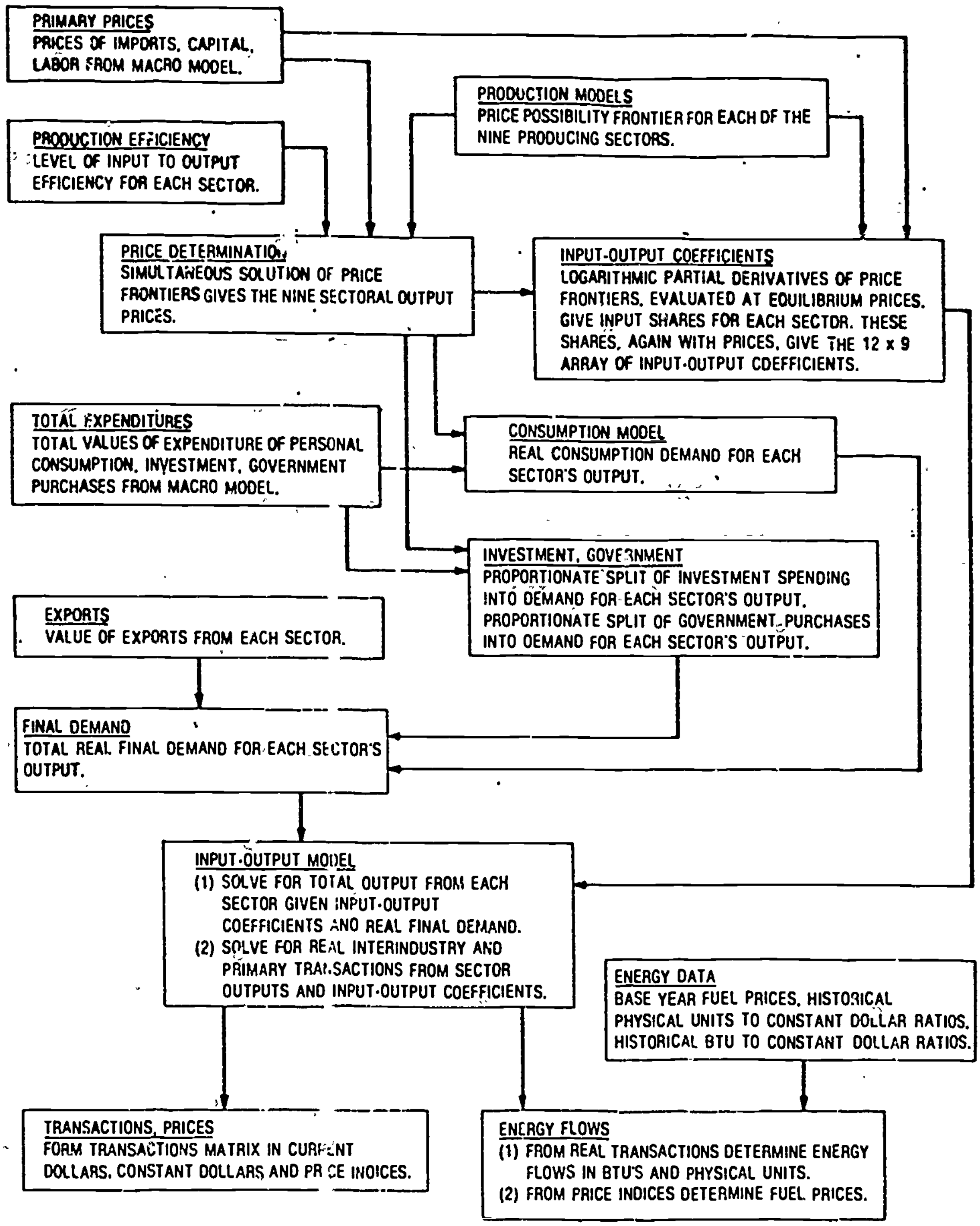

Figure A-1. Hudson-Jorgenson Interindustry Econometric Model: Diagrammatic Representation

General economy sectors
1. Agriculture, nonfuel mining, and construction
2. Manufacturing, excluding petroleum refining
3. Transportation
4. Communications, trade, and services

Energy sectors
5. Coal mining
6. Crude petroleum and natural gas
7. Petroleum refining
8. Electric utilities
9. Gas utilities

These nine intermediate sectors are integrated with four final demand sectors (consumption, investment, government, and exports), and three primary input sectors (capital, labor, and imports) to form the complete model. The Hudson-Jorgenson model seeks to remedy two major faults of previous models. First, conventional macro models are demand-oriented and other than the use of "price equations" have little to say regarding supply, especially in the long run when capacity generation becomes more critical. Second, the other main type of model in use, the input-output model, while having the capability to address the capacity question, relies on unrealistic technological assumptions, i.e. fixed coefficients.

The H-J model is composed of two main submodels--the interindustry model mentioned above, and a macroeconomic growth model which drives the industry model. The macro model consists of five behavioral relations which determine leisure demand, consumption demand, labor demand, investment supply, and the production possibility frontier which shows, for given levels of labor and capital input in the private sector, the trade-off between the production of private consumption goods and private investment goods. The macro model determines employment, output, consumption, investment, the wage rate, the price of capital services, capital stock, wealth, and leisure time. This is accomplished through identities and behavioral relations which are based on neoclassical conceptions of economic behavior and growth. The

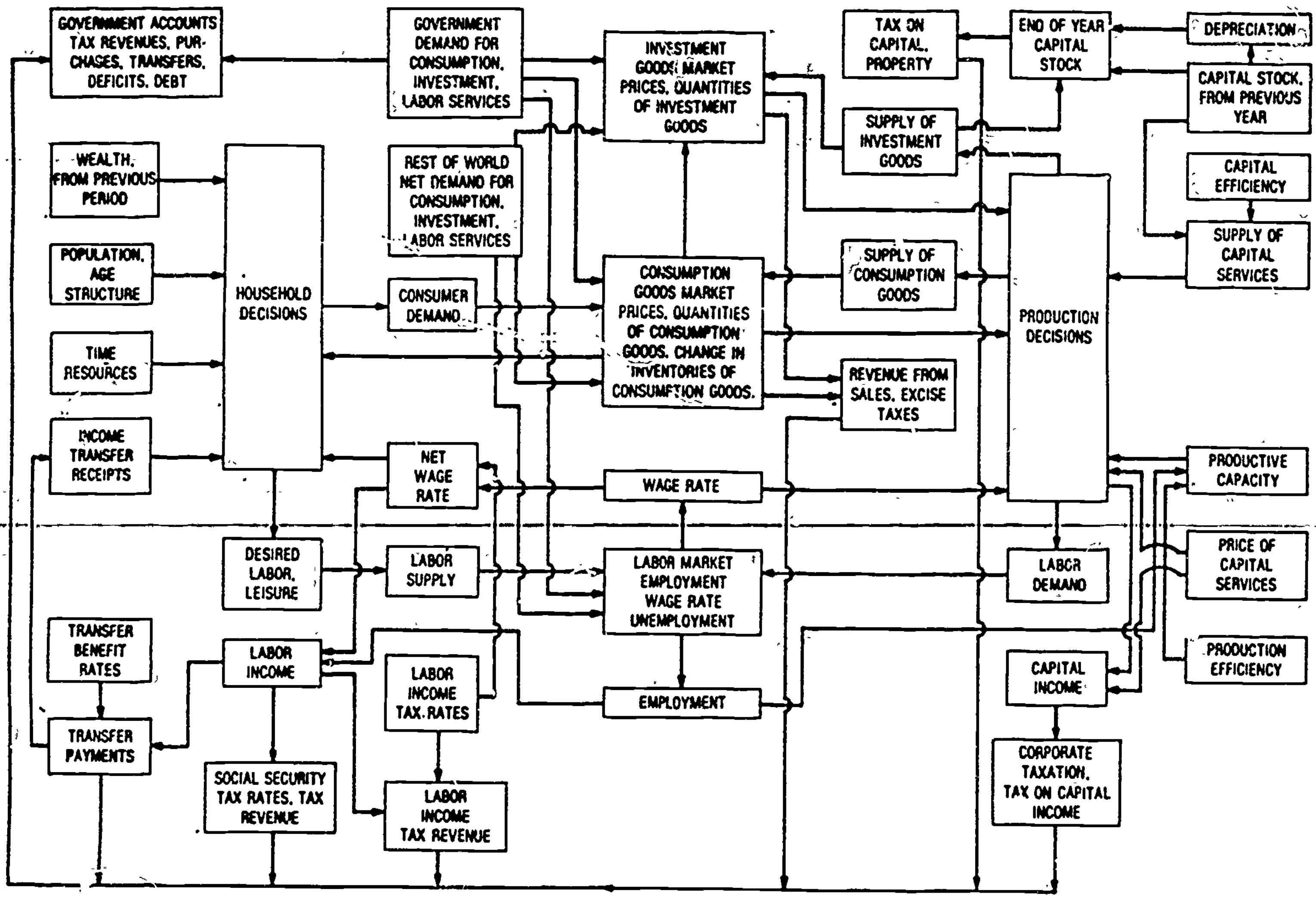

Figure -2. Hudson-Jorgenson Macro-Econometric Model: Diagrammatic Representation variables are the prices of imports, net exports, labor force, population and government purchases of goods and services. The bridges between the macro growth model and the industry model are the vector of final demands and the prices for labor, capital and imports. Total consumption expenditures, total investment expenditures, government purchases of goods, and exports are allocated to each industry by a series of fixed budget proportions for each sector. The sum across these four categories gives total final demand for each of the nine interindustry categories. These final demands can then be used in conjunction with the input-output coefficients to compute industry output levels and associated prices. However, for the Hudson-Jorgenson model, the input-output coefficients are not fixed, but vary as functions of input prices through the ingenious use of a factor price frontier and its related theoretical properties.

The factor price frontier in this model relates the price of output of each of the nine individual I-O sectors (including the energy sectors) to the price of capital (K), labor (L), energy (E), and materials (M). Hence, the name KLEM price frontier. These factor prices (for K, L, E and M) are themselves aggregate price indices. For example, the aggregate price index for energy is a function of the price of coal, price of crude petroleum, price of refined petroleum, price of electricity, and price of natural gas (i.e. the output prices of each of the five energy sectors). The same is true for the materials price index, which is composed of the output prices of the four non-energy sectors--agriculture, manufacturing, transportation and communications, and trade and services. These price frontier relations were first estimated in budget share form which imposed various restrictions on the parameters. Through various transformations relating to the mathematical properties of these relations it is possible to derive the input-output coefficients to be used in conjunction with the final demand levels to determine total industry output, labor demand, capital services demand, and all interindustry transactions and prices.

The model, as such, presents an elegant theoretical representation of an economy operating under the neoclassical paradigm with pure competition, profit and utility maximization, rational future discounting, complete divisability of capital goods, frictionless adjustments, and regular (and smooth) consumer preferences and producer production functions. However, it is these very neoclassical assumptions which are also the weakness of the model, as has been pointed out by Kuh [30], Dhrymes [17], and Sewell [39]. Adjustments by producers to changes in fundamental parameters (such as energy prices) are often not smooth and are frequently characterized by a great deal of inertia. The model, by intention, does not attempt to portray these adjustments. The consumption side of the model, by ignoring habit, is also guilty of the same charge. Furthermore, the consumption sector of the model with its linear logarithmic utility function (and hence fixed budget shares) implies unitary own-price and income elasticities and zero cross-price elasticities. The same is true of the individual investment functions. The translog price possibility frontier can best be defended as a second order Taylor series approximation to any continuous price possibility frontier. Kuh [30] has expressed three reservations about the translog function. First is the concern expressed above about the essentially static character of the implementation which ignores cyclical variation and inertia. Second, the particular version of the translog employed by Hudson and Jorgenson assumes constant returns to scale. As Kuh points out, even small departures from this assumption can, over a long period of time such as the model is used for, have substantial impacts. However, over time (between years) input productivities do change. Although strictly speaking, these changes are <u>not</u> returns to scale phenomena, they do have the effect of increasing output for a given level of input. Third, the translog was estimated with data from a time period 1947-71 in which there was little variation in cost-shares and input prices. This criticism could be leveled at almost any econometric model ever built, and although quite valid, is no more applicable to Hudson and Jorgenson than to any other model estimated from actual data. Dhrymes [17] has pointed out a number of problems, some of which are discussed above. One which is not is the question of whether or not feedback exists from the interindustry model to the macro growth model. Dhrymes maintains that the feedback loops are "closed" only if the sum of the individual (real) consumption quantities equals total real consumption. The same must also hold for investment. Unfortunately, the documentation of the model is not sufficiently precise to determine if these conditions are fulfilled.[2]

A.1.2. <u>The WEFA Annual Energy Model</u>. This model is the Wharton Annual Model (WAM) with a high degree of disaggregation in the energy sector.[3] WAM can be divided into nine major blocks: (1) final demand or GNP components, (2) input-output or interindustry transactions, (3) labor requirements, (4) wage determination, (5) value-added price sector, (6) wholesale price sector, (7) final demand prices, (8) other income sector, (9) monetary sector. The model is based on annual data and (although described sequentially) is fully simultaneous and is quite detailed.

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[2] Lack of adequate documentation is, as we shall see, a problem which plagues almost all the models reviewed. Hence, again, Hudson-Jorgenson should not be singled out. On lack of documentation, see also Lave in Hitch [22], pp. 278-301. In private correspondence with the authors, Edward Hudson has indicated that the model is, in fact, closed.

[3] Detailed descriptions of WAM can be found in WEFA [45] and WEFA [46].

The final demand or GNP components sector is composed of 67 categories of which 14 are consumption, 33 are investment, 6 are government, 6 are imports and 8 are exports. The consumption sector consists of demand relations for personal consumption expenditures (in real terms) for autos, furniture, other durables, food, clothing, gasoline, other nondurables, housing, natural gas, electricity, fuel oil, other household services, transportation services, and other services. The demand relations are typically of the relative-price real-income variety, frequently employing Almon lags. Additional explanatory variables include the ratio of the money supply to personal disposable money income, the money supply, the difference between the bond rate and the commercial paper rate, auto stocks, and housing stocks. The investment sector contains behavioral investment plant and equipment relations and capital stock-plant and equipment accounting identities for farm, ore and non-metallic minerals mining, coal mining, crude petroleum and gas mining, iron and steel, aluminum, other primary nonferrous, electrical machinery, non-electrical machinery, autos, nonauto transportation, cement, other stone clay and glass, fabricated metal products, lumber, furniture, instruments, food and beverages, textiles, paper products, chemical products, petroleum products, rubber products, apparel, leather, printing and publishing, transportation, utilities, communications, and all other. The other investment relations are for residential fixed investment and the change in business inventories. The main determinants of investment behavior are output prices, user costs of capital, industry output, and capital stock. The determinants are typically estimated using an Almon lag with length as far back as seven years. Capital stock and user cost of capital identities exist for each of the plant and equipment investment categories. The demand block is closed with six export categories (food, crude materials, manufactures, coal, other fuels, and services), eight export categories (food, crude materials, manufactures, crude oil, residual oil, natural gas, other fuels, and services), and six categories of exogenous government expenditures.

The interindustry transactions sector of WAM consists of 63 SIC industries.[5] Both the I-O matrix and the final demand bridge matrix are allowed to vary as functions of time and relative prices via an adaptive expectations mechanism. Given the I-O matrix and the final demand vector (converted to industry sectors via the bridge matrix), total industry output can be generated for each sector. These industry outputs are then used, along with capital stocks, as inputs into inverted production functions to give labor demands. These labor demand relations are estimated for 28 industrial sectors aggregated from 63 in the I-O table, and are the same as the 28 sectors for investment demand on the GNP side of the model. Similarly, manhour functions are also estimated for each sector. These labor demands are then summed over all industries to give total labor demand, which in conjunction with labor force equations yields the unemployment rate. Next, wage formation equations for each of the 28 sectors are specified. The specification follows the key sector approach.[6] Wage rates in the key sectors depend on prices (for cost-of-living adjustment), productivity and labor market conditions as represented by the unemployment rate. The wage rates in the remaining sectors then depend on wages in these key sectors, as well as price trends and the unemployment rate. Finally, in order to close the model, relations are needed for the three price

[5]It must be borne in mind that the final demand (GNP) categories do not correspond (one to one) to the SIC classification. For example, auto output (SIC-83) goes to consumer demand for autos, private business investment purchases of autos, and government purchases of goods, all of which are different GNP categories. Hence, a bridge matrix must be employed to transform the GNP demand to I-O sectors.

[6]These key sectors are autos, steel, textiles, petroleum and chemicals.

sectors: value-added prices, final demand prices and wholesale or I-O prices.[7] Prices for final demand (GNP components) are a bridge matrix weighted sum of the WPI I-O sector prices. The I-O prices are, in turn, a function of the value-added prices and the I-O prices from other industries. Using the I-O coefficient information and the value-added information for each identity, the vector of industry sector prices is solved simultaneously. Finally, the value-added prices are a function of industry unit labor and capital costs and rates of change of output. The model is then closed with the standard national income identities and a monetary sector.

The WEFA energy model also employs price-sensitive I-O and final demand bridge coefficients. The specification used relates flows from sector i to sector j to the difference between prices in sector i and j, to a time variable and to lagged flows. The estimation is done jointly for all sectors by constrained least-squares. Unfortunately, the procedure and its results are not documented. Hence, it is impossible to examine the results to determine, for example, the magnitude (or sign) of price effects on the I-O coefficients. While the WEFA energy model remedies one of the main defects of the Hudson-Jorgenson model by introducing lags in the adjustment process, it creates additional ones by the rather ad hoc nature of the specification, especially in the production sector. The extremely long polynomial lags (up to six years) found on the determinants of consumption and investment in the demand sector are also somewhat suspect.

Basically, the WEFA energy model is a disaggregated Keynesian system with an I-O sector as the supply side along with the labor force generated by population. However, the treatment of capital within the model is not

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[7]Severe data problems exist, especially with respect to I-O prices. See WEFA [46].

completely satisfactory. Investment and, in some sectors, prices are a function of the user cost of capital which in turn depends on the price of capital equipment, tax rates, and depreciation rates. Capital stock enters only as a lagged value for depreciation in the investment and labor demand equations. Hence, the level of capital stock plays no direct role in determining output since labor is related to output only through the demand-income side. Furthermore, in the employment and manhours demand relations the sign on capital stock is positive in some relations, negative in others. If the relation is an "inverted" Cobb-Douglas then the sign on capital should always be negative. Also, the output variable entering the inverted function is value-added output. Hence, intermediate sector effects are excluded from the labor demand equations.

A.1.3. <u>The BLS Growth Model</u>. Since 1966, the Office of Economic Growth of the Bureau of Labor Statistics has published long-term projections of output and employment by industry. These projections provide a framework for employment projections by occupational category, and also serve various needs of the Labor Department's training and job programs. Projections with the system are typically for 5 or 10 years into the future, and are made as point estimates with cyclical adjustments being largely ignored.

In outline form, BLS long-term projections derive from the coupling of a macroeconomic model with an input-output system. In practice, the model is best described as a set of well-defined procedures, operated in recursive fashion. A brief description of the projection procedures follows, succeeded by discussion of the methods and the capabilities of the model.

The main steps in making a set of projections are the following:

1. Supply GNP is estimated in real terms.

2. Demand GNP is estimated together with incomes and prices.
3. Demand and supply are balanced by adjustments of fiscal policy variables.
4. Aggregate demand components are distributed to detailed industry sectors.
5. Given trade margins, industry outputs are determined.
6. Given assumptions about hours worked and average productivity, a set of labor requirements is derived from industry output estimates.
7. Given capital/output relationships, a set of capital requirements is derived from industry output estimates.
8. Industry output, employment and capital requirements are balanced within the input-output block, and employment estimates are made consistent with the macroeconomic estimates through an informal iterative process.

In carrying out a projection exercise within this framework a large number of variables are explicitly or implicitly exogenous, either by estimation or by procedure. Consequently, much of the formal consistency which is normally imposed by a model solved simultaneously is attained only up to some approximation in the recursive steps actually followed. As an economic tool, the crucial probable weakness of the BLS model is that the solution adjustment methods may fail to correspond to the kind of adjustments which would actually occur through the price mechanism in equilibrating market solutions. Some further detailed description of key steps in the process aids in bringing out the "model" aspects of the procedures followed.[8]

Supply GNP. Conceptually, supply GNP projections are derived within the framework of an aggregate production function. The following steps are included:

a. Labor force growth. From Census Population Survey data, participation rate projections, and projections of female group fertility rates, total labor force projections are derived. Present procedures do not, however, link these estimates formally with endogenously generated variables in the macro-

[8]The most complete documentation of the BLS procedures is found in Kutscher [31] and BLS [11].

economic model which affect, for example, labor force participation rates. An estimate of Armed Forces is netted from the total labor force to produce an estimate of the civilian labor force.

b. Total employment. The aggregate target unemployment rate is an assumed variable. Together with the civilian labor force estimate, this gives an estimate of total employment, on a household survey basis. This figure is then adjusted to conform with an establishment basis employment concept. Next, total employment is broken down between farm, private and government sectors, assuming shares for each, in order that individual productivity and weekly hours estimates can be applied to each component of total employment in generating aggregate manhours input into the production function.

c. Private sector manhours. Productivity and average weekly hours estimates for the private nonfarm and farm sectors are used to generate total private manhours.

d. Capital services. The capital input into the production function for real private GNP is derived from the capital stock and net real investment. Net investment is a function of private sector output and corporate cash flow, among other variables. The corporate profits tax rate is the only policy variable affecting cash flow. Depreciation rates, investment tax credits, etc., are not formally treated in the model.

e. Total supply GNP. Private sector capital and labor inputs determine private sector real GNP within the production function. Added to this is an estimate of real government sector output (the mix of estimated government employment times corresponding real wage rates), giving total real GNP. Although steps a-e are followed theoretically, BLS applications suggest that implicit productivity estimates from the production function are often suppressed in favor of an exogenously given rate of productivity growth. The latter is then multiplied by total manhours to produce private real GNP. In this approach, problems related to consistent estimation of income and supply GNP (and hence investment and capital stock determination) are short-circuited. An examination of steps a-e indicates that most of the supply projections are derived by ad hoc methods, rather than from specified behavioral relationships. This makes a large part of the macroeconomic projections judgmental in character.

Income and Demand GNP. Income determination in the model involves a relatively simple set of relationships specified primarily to determine personal and disposable incomes. A simple wage-price block is embodied in which private sector prices are related to unit labor costs and the PCE deflator. A function for compensation per manhour together with the productivity estimate determines unit labor cost, and the PCE and private sector deflators are linked through a simple correlation.[9] Energy price variables do not enter the macro model price determination process as they do, for example, in the current versions of the DRI macro model.

Items which comprise corporate cash flow are made common to both supply and demand GNP determination, and in operational terms appear to be essentially exogenous income estimates. Most policy variables in the model appear in the income determination block as tax and transfer items, and include the following:

1. Federal tax rate on gasoline
2. Employer-employee combined tax rate for OASDHI
3. Coverage ratio for OASDHI
4. Taxable wage base for OASDHI
5. Average employer contribution rate for unemployment insurance
6. Federal tax rate on median family income
7. Transfer payments

[9] Barth [2].

In terms of policy variables, the model is structured pretty much as a fiscal policy model. It contains no monetary sector, and only two exogenous interest rates enter as proxies for monetary sector activity. An exogenous estimate of publicly held debt is also included as a determinant of interest income.

Consumer demands are largely determined by disposable income, while investment demand is estimated as a factor demand. Government demand and net exports are exogenously determined. Any gap between supply and demand GNP estimates at the aggregate level is eliminated through fiscal policy adjustments--either changes in expenditures, or changes in taxes, transfers, etc. It is important to note that, in economic terms, this sort of equilibration amounts to saying that product and factor prices will not be the primary determinant of the equilibration process. This process, relying on adjustment of fiscal policy variables, is more akin to a planning model. In addition, since there is no formal monetary sector, the consistency between adjustments of fiscal policy variables and interest rates is highly questionable. The main reason all the adjustments are made to income and demand is that initial values of labor force utilization (the employment rate) and capital services are exogenous, making the Phillips curve price determination model largely inoperative in altering product and factor demands in terms of the price adjustment mechanism.

Industry Sector Output and Employment Detail. The input-output block of the BLS model executed by developing a "bill of goods" for each aggregate demand component determined by the macro model which, in turn, establishes a vector of final demands by industry sector.[10] Consumer demand is allocated over some 82 demand categories through use of a modified version

[10]BLS [11].

of the Houthakker-Taylor demand model.[11] A "bridge" between these demand categories and producing industry sectors is then established. Estimated margins for transportation and distribution enable these final demands to be converted into estimates of final demands at the producer output level. The allocations of investment, inventories and Federal government expenditures are made in a less formal manner than consumption, depending largely on historical trends in expenditure shares relative to private sector GNP growth. The allocation of state and local government expenditures by industry sector is somewhat more formal, as the macro model provides a breakdown between expenditures for education and non-education categories, and an allocation between employee compensation and purchases of goods and services. In addition, a submodel currently under development will derive purchases and employment in terms of eight end-use categories.[12] Export demand is allocated according to past trends and other judgmental factors. For imports, a split is made between intermediate requirements and final demand purchases, and between competitive and non-competitive imports, i.e. if imports are a substitute for similar domestic output, they are allocated to consuming industries in parallel fashion. It may be noted that the determination of intermediate imports, and the resulting coefficients matrix relating these imports to the level of output, has important implications for the model's portrayal of the economy's supply behavior. This is particularly true since energy imports have begun to play a larger role as a potential constraint on the U.S. economy's supply potential.

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[11] Houthakker and Taylor [183].

[12] An extension of the BLS framework in the area of specifying the functional detail of government expenditures has been made by Bezdek [9]. The greater detail, however, requires increased use of <u>ad hoc</u> methods to derive appropriate, corresponding price measures.

The vector of final demands multiplied by the I-O inverse produces estimates of industry output requirements. Similarly, matrices of industry employment-output ratios and capital-output ratios together with the I-O inverse permit estimates of employment and capital requirements to be made, by industry. Alternate employment estimates can also be made by converting industry output requirements using estimated average productivity and annual hours assumptions.

Adding Up and Feedbacks. Documentation of the BLS model indicates that a feedback and balancing procedure is employed to achieve consistency between micro and macro projections of employment, investment and imports.[13] In practical application, however, most of the reconciliation appears to take place within the I-O model, rather than between the macro and I-O blocks. For example, in balancing imports against the industry pattern of aggregate import demand, both the distribution of imports by sector and the intermediate coefficients are adjusted in *ad hoc* fashion. Moreover, it appears that aggregate imports in the macro model are derived from the detailed industry bill of import goods and services, rather than from a macro import demand function. Similarly, for investment, it appears that aggregate requirements are essentially exogenously determined as a component of demand GNP, and that any factor demand concept theoretically embodied in estimating supply GNP is not rigorously tied to underlying implied industry level factor demands of assumed capital-output ratios. Finally, the sum of industry employment requirements is made to accord with aggregate unemployment implied by assumed labor force and unemployment rate values used in estimating supply GNP. In practice, most adjustments are usually made in the assumed industry average productivity

[13] BLS [11], p. 34.

coefficients rather than in the aggregate unemployment rate, which would imply price adjustments, therefore demand distribution adjustments, etc. In this system, also, no consistent relationship is established between the assumed aggregate productivity (or that which is implied by the aggregate production function) growth rate, and the assumptions underlying the industry productivity growth rates.

Evaluation of the Model. The methodology of the BLS projections places more emphasis on the detail than it does on modeling the behavior of the economy at any given level of detail. Within the framework of the projections methods, it has been shown that the largest source of error in industry employment projections stems from errors made in estimating industry employment-output relationships.[14] In general, the contribution of errors made in the I-O block to a total forecast error were greater than those attributable to errors in final demand forecasts. Moreover, as might be expected in a large system, many errors at the industry level offset each other, so while overall errors might appear acceptable, very large errors could be occurring at the sectoral level. It has also been found that the total BLS model does not produce significantly better estimates of industry output and employment than do more naive, single-equation regression methods.[15] Much of this result is attributed to the fact that so many key economic variables are either assumed exogenous, or projected as if they were exogenous--in effect, though the detail is great, the behavioral model as such is very simple, and very responsive to initial values chosen for exogenous variables.

The most important deficiency in the BLS model is in the area of

[14]Personick and Sylvester [37], p. 14.

[15]Personick and Sylvester [37], p. 23.

consistent price determination processes between micro and macro behavior. The BLS model is primarily a model of relationships between real quantities--labor force, employment, real output, etc. Prices enter the model in the income block, primarily because many policy variables affect income items, and are in nominal terms, and because the demand equations require an estimate of real rather than nominal disposable income. Hence, the price mechanism is a simple Phillips curve model designed to generate a PCE deflator for converting nominal disposable income into a constant dollar estimate. Although the modeled price determination process is highly aggregate and straightforward, most of the procedural adjustments made to "balance" or solve the model imply price adjustments and technological adjustments. However, there is no way to determine what kind of price adjustment behavior is implied by the methods. Consequently, it is difficult to judge the economic reasonableness of the real resource allocations implied for the growth of output and employment at the industry level.

At the present time, work is underway at BLS to compensate for some of the deficiencies in the price determination process. In particular, efforts are being made to adjust input-output coefficients for changes in relative prices. However, this is only one area of deficiency in the model's price determination process. For example, since energy prices have changed radically, a number of relative price changes can be presumed to have taken place both in final product markets and in factor markets. Consequently, price effects from energy would have altered the composition of final demand, the mix of outputs with an industry sector, and the mix of inputs. This would obsolete some of the price relationships implied in existing "bridge" tables, presently based on 1970 demand patterns. Another source of change in relative price relationships which would be particularly affected by intraindustry output shifts is in the markup relationships assumed to hold for transportation and distribution margins. These relationships, too, are likely to be substantially altered from 1963 or even 1970 values, as a result of changes in energy prices.

In its most recent projection, BLS has made adjustments in basic assumptions about productivity, unemployment and inflation. As they state it:[16]

> "Some of these alterations were made because of the changed energy outlook. The new projections, unlike the 1973 set, do not assume the availability of relatively cheap, nearly unlimited energy supplies. The effects of the changed energy outlook on labor productivity, capital requirements, and prices, as well as the relationship of these changes to economic growth, are complex issues.
>
> Although a great deal of effort was devoted to these questions, BLS has not developed a satisfactory method of dealing with them in the industry and employment projections."

In addition to finding a method for adjusting I-O coefficients for relative price changes, the BLS macro model could also be modified to incorporate energy into the projections in a simple way, as has been attempted in other macro models. This could be done by introducing an energy variable into the aggregate production function, or the cost function "dual" of the production function--i.e. in the price equation. If employment demand is then made endogenous, solution of the macro model would then give some indication of feasible sets of price, output, employment, productivity and demand configurations compatible with a given set of energy price assumptions. A second, somewhat more ambitious project would involve estimation of production functions for the key industries which produce intermediate outputs in the economy. In this way, real wage rate changes in various inputs would cause

[16]Kutscher [31], p. 6.

factor demands to adjust in response to price variations.[17]

A.1.4. The ETA-MACRO Model. The ETA-MACRO model is an extension of the energy technology assessment model (ETA) developed by Alan Manne.[18] A macro-economic model (MACRO) providing for substitution between capital, labor and energy inputs, has now been grafted onto a modified version of ETA. The over-all scheme is a dynamic, nonlinear optimization model designed to evaluate the feasibility of fuel substitution and technology choices for horizons up to 75 years. ETA-MACRO is specifically designed to analyze interdependences between the energy sector and the economy as a whole. The implications of energy supply constraints on investment and GNP growth can be evaluated in view of various assumptions regarding long-run substitution possibilities between energy and other inputs which define supply GNP.

The MACRO Submodel. Whereas the earlier ETA model took GNP growth as exogenous, ETA-MACRO generates supply GNP endogenously from the production function. The production function is a "nested" CES, with input pairings for capital and labor (K, L) and for electric and non-electric energy inputs (E, N). Thus, gross output is defined by the inputs, K,L,E,N, and the parameters of the functional form. The conditions imposed on the functional form of the production function are as follows:[19]

a. there are constant returns to scale;

b. there is unitary elasticity of substitution between one pair of inputs--capital and labor--with the optimal value share of capital, α, being given within this pair;

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[17] Such work is currently being undertaken by Dale Jorgenson for a 35-sector I-O model.

[18] ETA-MACRO is documented by Manne [33], pp. 1-45. An earlier version of ETA is described by Manne [32].

[19] See Manne [33], p. 5.

c. there is unitary elasticity of substitution between the other pair of inputs--electric and non-electric energy--with the optimal value share of eleccricity, β , defined within this pair; and

d. there is a constant elasticity of substitution between these two pairs of inputs--the constant denoted by σ .

Key parameters for the production function are given exogenously as follows:

α = .333 = capital's value share

β = .40 = electricity's value share

σ = .25 = elasticity of substitution between energy and non-energy inputs

Other values are, of course, possible and lead to quite different results. The above values are based on the author's judgment and are not based on econometric estimation. Labor force and productivity growth (at constant energy prices) are given exogenously, and energy input values for E and N are provided by the ETA submodel. Capital accumulation is provided by gross investment less discards, where lags are introduced between gross investment activity and changes in the useable capital stock.

The model optimizes the pattern of consumption and investment over successive time periods. Consumption is defined as the difference between GNP and the investment and energy inputs. Using a logarithmic utility function, a discount factor is applied to the "utility" of consumption to reflect time preferences with respect to present versus future consumption (thus higher or lower rates of saving and investment). Consistency between the utility discount rate, which is the key saving parameter, and the marginal productivity of capital defined by the production function is achieved conceptually by a simple formula suggested by Ramsey. A 10 percent discount rate is used.[20]

[20] See Manne [33], pp. 27-28. Experiments with alternative values of the discount rate (8 and 12 percent) suggest that many energy policy results may turn out to be invariant with respect to aggregate saving rate behavior, or so at least the model would indicate.

The key exogenous factors driving the MACRO model are the saving-investment process (the utility discount rate), the growth of the labor force (and its productivity at constant energy prices), and the elasticity of substitution, σ , between energy and non-energy inputs. The latter two factors dominate the behavior of MACRO. It should be noted that the overall model results are very sensitive to values chosen for the production function parameters. The author discusses the implications of alternative values of the elasticity of substitution. In general, higher elasticities permit more flexibility in the substitution of resources. Therefore, any given energy supply constraint creates a smaller impact on GNP growth. The author does not discuss the implications of alternative values for elasticities within nested pairs (e.g. between K and L, or between E and N). The unitary elasticities assumed may not be plausible, particularly for sectors such as manufacturing (some studies have shown these substitution elasticities to be significantly less than one for the more capital-intensive industries). A second factor not discussed is the role of technical change in the long-run production function. It is not clear what, if any, consistency exists between the technology changes in the energy supply submodel and technical changes implicitly embedded in the aggregate production function, as specified. However, it seems reasonable to suppose that major technological shifts in the energy supply sector would have important implications for both technical change in the aggregate and the substitution elasticities among production factors, both within and between "nests."

<u>The ETA Submodel.</u> The ETA model is structured so as to interface two basic demand categories--"electric" and "non-electric"--with energy supplies. A total of sixteen technologies is specified for energy supply. Electric power is generated from coal, nuclear, hydroelectric and other advanced tech-

nologies such as solar power. Non-electric power is generated from oil and gas imports, domestic oil and gas, oil shale, synthetic fuels and electrolytic hydrogen conversion. Basic fuel supplies are specified, therefore, in the form of coal, oil and gas, uranium, shale, and other. Prices of primary energy are given, along with own and cross-price elasticities of demand. The GNP path from MACRO determines overall energy demands. Constraints take the form of energy conversion factors, and capacity or expansion rates in the energy sector. The optimization process approximates perfectly competitive conditions, where prices are equated to marginal costs and fuels are used up to the point where price to marginal product ratios are equated across alternative fuels. Thus, given demand, technology and fuel mix choices are made which minimize the total cost of satisfying that demand. Given exogenous assumptions, the ETA model determines the time path for alternative supply modes--the expansion or decay which satisfies demand requirements. Substitutions between electricity and non-electric energy take place in response to shadow prices determined through the optimization process.

The labor input is not specified in the ETA process model, but only shows up in the macro production function. Labor costs are embedded in exogenous estimates of current annual operating costs for technologies specified in ETA. If these costs were decomposed, factor demands for labor could be attached to the ETA's process sectors. However, as these are generally capital-intensive technologies, the derived labor requirements would probably not be large. Implied in the MACRO sector production function is a labor demand relationship. Using the marginal productivity relation, this labor demand function could be derived.[21] Given trends in average hours worked,

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[21]This would also imply adding wage and price determination relations to the model.

these results could be converted into employment estimates. Unemployment, or deviations from full employment could be evaluated if labor force growth is specified. It might be interesting to solve ETA-MACRO in this way, for alternative assumptions about supply constraints and long-run substitution possibilities, in order to determine what kinds of flexibilities the economy's structure needs to portray in order to keep the labor force fully employed.

A.1.5. <u>The INFORUM Model</u>. The work begun by Clopper Almon at the University of Maryland's Interindustry Economics Research Project has evolved over time into the current INFORUM model.[22] Support for the model's development has come mainly from private sector sources, and the main use of the model has been in making industry forecasts. INFORUM is a 185-sector input-output model designed to produce annual projections over a 10 to 15-year time horizon. In earlier versions, the model was primarily a "real" model, without a wage-price-income determination mechanism, and without a financial sector. More recent versions include income and price level determination, but financial variables, mainly interest rates, remain exogenous. Other main exogenous variables are the labor force, exchange rates, world income or activity, and Federal government expenditures.

The model incorporates a considerable amount of detail in the breakdown of government expenditures by functional category. Similarly, extensive detail is provided for the functional specification of construction industry investment (structures), and for capital equipment investment. Five functional categories are given for exogenous Federal government expenditures. Four detailed categories of state and local government expenditures are given,

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[22]See Almon, <u>et al</u> [1].

specified endogenously by functions relating expenditures to variables such as population, school-age population, and real disposable income per capita. Construction investment is specified for 28 private and public investment activities, with endogenous relationships determining 22 of these. Energy-related construction activity is specified for (exogenous) oil and gas exploration, electric and gas utilities, and pipelines. Equipment investment is modeled for 90 sectors (combination of the 185). Investment behavior is a function of output, the cost of capital, and lag adjustments. The "user cost" of capital includes tax and depreciation rate information as policy variables.

A principal reason for formally including investment functions in the model's structure is to provide for a linkage between labor productivity growth and the growth of the capital stock per worker. In practice, however, a number of methods are relied upon to determine projected values of labor productivity, so the applied model is somewhat less rigorous than the theoretical construct. The productivity estimates, together with output projections determine employment for the 90 industry sectors in a fashion quite similar to that of the BLS long-term growth model. In solving the model, iterations are made back-and-forth between industry output-productivity-employment estimates and final demand, with most adjustments being made in consumption (i.e. the saving rate).

Many of the technical adjustments in response to prices in the economy are introduced into INFORUM via ad hoc methods and judgment. Logistic curve fitting provides some guidance in the adjustment of input-output coefficients over time, as a proxy for price and technology effects. Similarly, in consumer demand patterns, cross-sectional information is used to check or replace time series estimates of income elasticities, or elasticities are specified

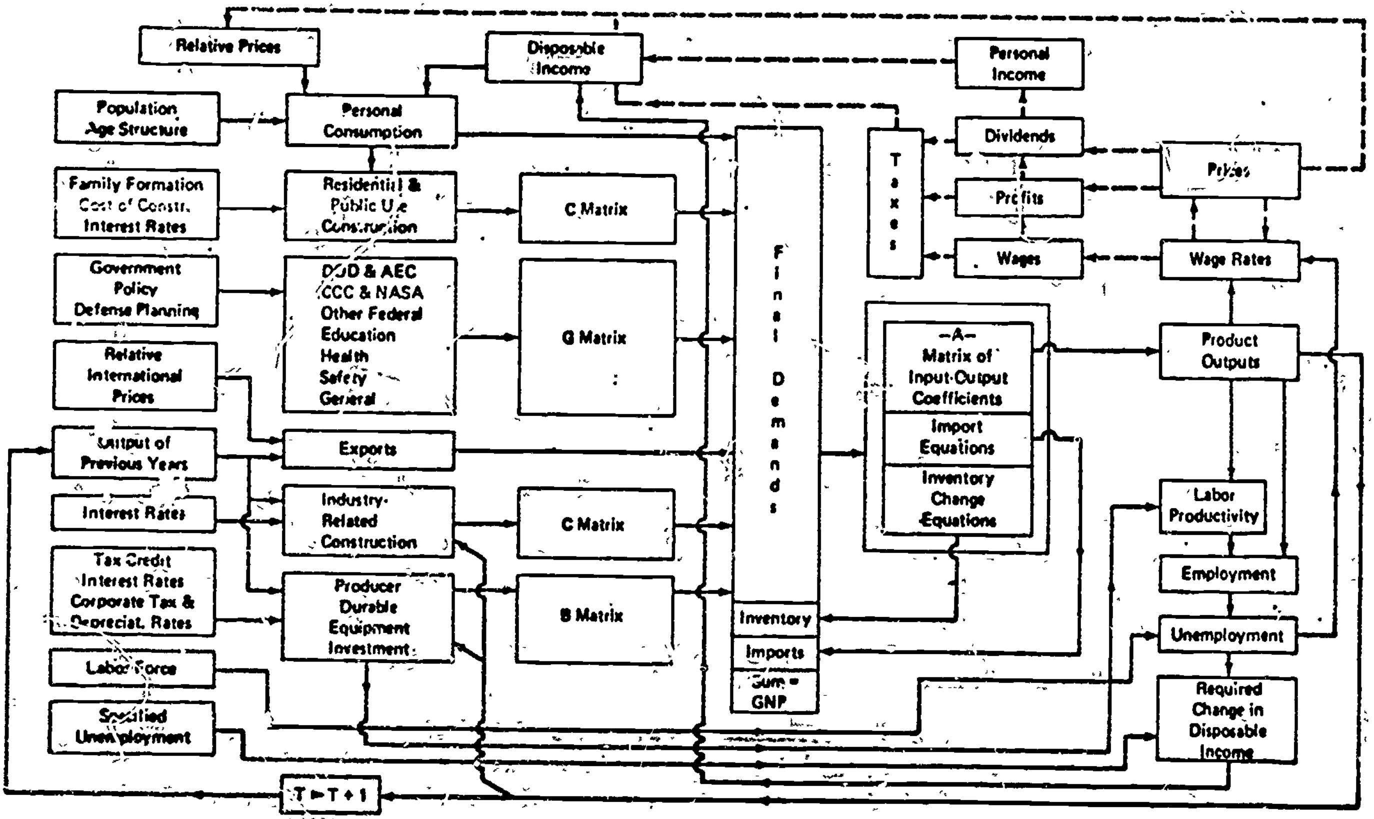

Figure A.3. INFORUM Model: Diagrammatic Representation exogenously according to other information. As with a number of input-output models, a main deficiency of INFORUM in the current context is that price effects are not consistently modeled, as between intermediate and final demand blocks of the model and, in general, the price determination process is inadequately specified.

INFORUM has been tentatively applied to the study of selected energy-related problems. For example, Blankenship, et al [155] used the model to study the embargo and the drawdown of strategic petroleum reserves. This was done by taking assumed price elasticities for consumer demand categories and converting energy price changes for crude oil into changes in consumer demands. Changes in output and employment were then calculated from the implied changes in final demand by the model. This exercise suggests that INFORUM has not yet been successfully adapted, in formal terms, to the study of energy sector changes upon the general economy. With a lot of judgment the model can, however, be used to calculate effects of near-term quantitative shocks to the economy in broad terms.

A.1.6. Other General-Economy Energy-Sector Interactions Models. Other energy modeling efforts related to the general economy are those of Kennedy and Neimeyer [28], Hnyilicza [25], the PILOT model,[23] and Data Resources Inc. (DRI). The DRI model, somewhat like the WEFA energy model, is based on an extension of an existing econometric model of the U.S. economy.[24] The DRI model treats residential, commercial, industrial and transport electricity demand regionally for 13 regions corresponding to the Petroleum Administration

[23] See Dantzig and Parikh [16] and Parikh [35].

[24] The DRI energy model is proprietary and is undergoing extensive modification. Hence, documentation on the current version was not available at the time of this writing.

for Defense Regions and the Census Regions. Electric utility demand for coal, petroleum, natural gas, nuclear power and hydroelectric power is also treated regionally along with residential, commercial, industrial natural gas demand. The Hnyilicza model divides the economy's output into two sectors: energy and non-energy. Output for each sector is then treated as a function of labor, capital, energy, non-energy and imports. The PILOT model is an optimization (linear programming) model covering 18 industrial non-energy sectors and five energy sectors. The model seeks to answer questions concerning physical flows of energy and has as its objective the maximization of a price weighted sum of industry outputs. Prices do not vary within the model.

A.2. Energy Sector Models. This section surveys those models which deal with all of the various energy sectors (oil, gas, electricity, etc.) but do not treat their interactions with the general economy. For example, income and non-energy prices, to the extent they enter these models, are assumed to be unaffected by energy prices and quantities. These models have the advantage that they portray individual energy industries in greater detail than the general-economy energy-sector interactions models. Models reviewed under this section include: (1) Decision Focus Inc. (DFI)-Stanford Research Institute (SRI)-Gulf Corporation Energy Model, (2) Bechtel Energy Supply Planning Model (ESPM), (3) Lawrence Berkeley Laboratory Models (LBL), (4) Project Independence Evaluation System (PIES) Model, and (5) the Brookhaven National Laboratory's Brookhaven Energy Supply Optimization Model (BESOM).

A.2.1. The DFI-SRI-Gulf Energy Model. This model is a highly detailed dynamic regional model of the U.S. energy supply sector. Originally, the model was developed to enable the Gulf Oil Corporation to assess the viability of synthetic fuels production. Since then, the model has been expanded considerably and has been widely used by several Federal government agencies, the Electric Power Research Institute, and various private sector firms.[25] Presently, versions of the model are being further developed, independently, by Decision Focus Inc. and SRI. SRI is also developing a world energy model based on a similar methodology.[26]

Model Structure and Outputs. The model is designed to evaluate the viability of alternative energy supply technologies over a 50-year time horizon. End-use energy demands are given, and choices between competing energy conversion, distribution and primary resources are determined on the basis of relative prices which, in turn, are determined by individual demand and supply schedules. The outputs of the model include the time path of prices and quantities of various energy forms. Also produced are the capacity additions in various activities needed to supply intermediate and final energy demand plus transportation and distribution facilities.

The model incorporates 17 end-use demand categories, for each of nine U.S. census regions, and currently contains about 2,700 separate processes (or activities) within its structure. Each activity has a price-cost relationship in which price is determined by fixed and variable cost items. Input-output relationships among activities determine derived demand requirements. Output requirements relative to existing capacity along with discounted profit streams determine capacity additions over time. Profits are given by price-cost relationships. Capital costs are influenced by exogenously provided tax rates. Costs of secondary materials required in main processes are determined endogenously through simple lag relationships between capacity utilization,

[25] For example, see the report of Synfuels Interagency Task Force [40].

[26] Cazalet [56].

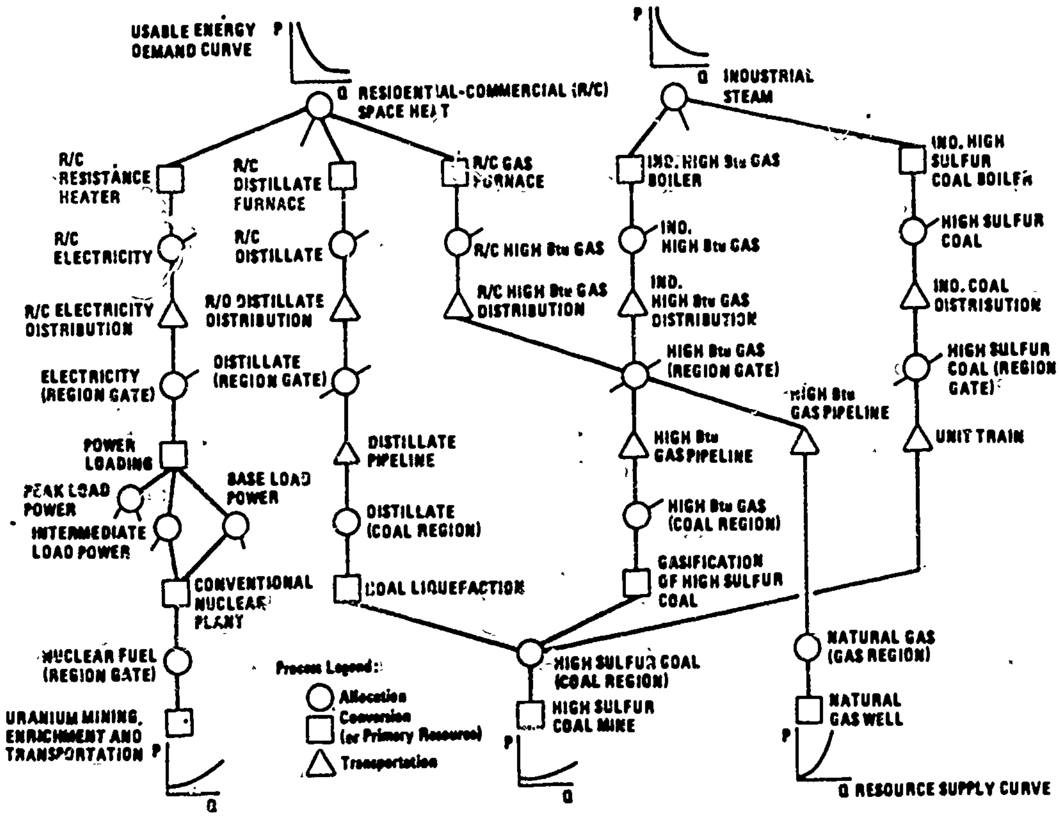

Figure A-4. DFI-SRI-Gulf Model: Diagrammatic Representation price and capacity additions in the secondary inputs sector. Prices of secondary inputs then enter the computation of capital costs for the main activities. Important lags are introduced into the supply dynamics through relationships which specify capacity additions and retirements, and through lags in the price-output adjustment process.

The main exogenous variables and parameters entering into the model include the following:

- Technical input-output relationships, and thermal efficiency conversion relationships
- Cost estimates for new technologies
- Growth in end-use demand, by region, as related to regional GNP growth, and population growth
- The aggregate inflation rate in the economy
- Required economic rents in primary production activities
- Discount or interest rates
- Growth in potential reserves of basic resources
- Imports of crude oil or other energy forms
- Regulatory or other constraints on the adjustment of prices or costs
- Assumed lag relationships
- End-use demand elasticities

The model solves iteratively until a set of output levels and prices is determined for all activities which satisfies the final demand requirements. In addition to determining an efficient supply allocation, the model output indicates how much capacity expansion is required over time in various activities. However, direct labor inputs are not presently included in the input framework, although the model structure would permit this if labor-output estimates for various activities were specified (as, for example, in the Bechtel energy supply planning model).

Evaluation of the Model. The SRI-Gulf model attempts to tie together the advantages of a detailed structure of the energy supply sector, using engineering data on costs and technology, with the advantages of a supply-demand model which determines market-clearing prices for various activities.

The model's great detail permits easy modification to represent the introduction of new technologies, limitations on basic resource supply (foreign or domestic), and the operation of government regulations.

The principal limitation of the model lies in the reliability of estimates of various parameters (such as in lag relationships) and in the specification of functions which determine prices and capacity expansion. Limitations in the price determination process are particularly important, since prices (and lag effects) determine market shares or activity levels, which determine output requirements, capacity additions, etc. Capacity additions, in turn, are related to capital costs and total costs over time. Other aspects of the price-cost determination process also present difficulties. Economic rents, discount rates and interest rates are assumed, as is an economy-wide inflation rate. The latter is used to "move" a number of costs and prices in the model over time, but linkages between the economy-wide inflation and interest rates or rental values are not addressed. In addition, although engineering information may permit estimation of regional differences in costs of various activities (as in extraction or power conversion), it is not clear that the model specifies similar differences for price or cost formation. Thus, the effective amount of information with respect to price formation processes may fall considerably short of the detail in the model permitted by engineering data.

Because the dynamics of price-cost and capacity change are determined by simple lags and rate-of-growth assumptions, rather than by estimation of actual cost functions from data, the optimizing allocation of supply activity via prices appears less appealing as a practical result than one might expect. A useful test for this model would be to compare actual and predicted allocations and capacity additions over time.

A.2.2. <u>The Bechtel Energy Supply Planning Model (ESPM)</u>. The ESPM was developed by the Bechtel Corporation for the National Science Foundation and the Energy Research and Development Administration. The model was designed to estimate regional requirements for capital, manpower, materials and equipment. The main intended use was feasibility analysis of various national energy scenarios in the 1975-1995 time frame. These scenarios included the depiction of annual incremental requirements for various inputs needed to supply the overall energy demanded by the economy.

The ESPM model simulates a detailed energy supply system including 91 types of energy extraction, processing and transportation facilities. It determines requirements for 75 categories of capital, manpower, materials and equipment for each of 14 regions. The model is basically an accounting tool and is not constrained in any way by the availability of the input requirements derived from the exogenously given fuel mix associated with end-use demands. Facility requirements are modeled for the supply of energy in various forms from coal, natural gas, crude oil, oil shale, nuclear, hydropower, geothermal, solar and solid waste sources. Numerous conversion facilities are modeled which describe the conversion of basic energy sources into final fuel and power forms at end-use, e.g. gasoline, electricity, heat, etc. The model contains a total of 251 detailed energy flows--by type and by region--and 66 types of facilities in the energy sector, and 25 types of transportation facilities. Outputs of the model are "direct" requirements only, derived from engineering data which specify the input-output relationships in physical or cost terms for each activity. Gestation periods associated with planning and construction of facilities are also specified in the model. These data were derived from actual experience of various divisions of the Bechtel Corporation involved in the design and construction of many of the facilities, and from other industry contacts and technical literature. Much of the data was developed jointly with the Stanford Research Institute.[27] The ESPM model includes considerable detail with respect to direct manpower requirements associated with the building of energy extraction and conversion facilities. The attached table indicates the detail contained in the model. The "Reference Case" referred to in the tables is the FEA's base projection presented in the "1976 National Energy Outlook," Appendix F. Fuel demands and location coefficients for energy supply facilities were generated by the FEA-PIES model, and were made definitionally compatible with the ESPM model.[28] The detailed occupational manpower demands generated by the ESPM model demonstrate one of the key advantages of process-type models, namely, that if the requisite data are available and the input-output relationships are plausible, direct manpower requirements associated with expanding the U.S. domestic energy sector can be derived explicitly by the model. Since the model estimates refer to labor requirements, they do not indicate anything about how labor markets balance supply and demand. Consideration of supply conditions could, in reality, impose constraints on construction of facilities. Experience has shown that most manpower projections suggest impending shortages of particular types of personnel, but in reality such shortages have not materialized as initially projected because of various labor market adjustments.[29] On the other hand, one reason that labor shortages have not materialized thus far is that the overall economy is operating well below full employment. A company survey of manpower supply-demand matchups suggests

[27] Carasso and Gallagher [54], p. 5.

[28] Gallagher and Zimmerman [175], pp. 2-5 to 2-8.

[29] Gallagher and Zimmerman [175], p. 8-5.

GROWTH IN MANPOWER REQUIREMENTS FOR THE OPERATION AND MAINTENANCE OF ENERGY-RELATED FACILITIES FOR THE REFERENCE CASE (@)

(man-years/year)

CATEGORY	ANNUAL REQUIREMENTS				AVERAGE GROWTH RATES (%/YEAR)		
	1975 (CALC'D)	1976-85 AVG	PEAK	(YEAR)	1975-80	1980-85	1975-85
CHEMICAL ENGINEERS	2069.	2324.	2796.	(1985)	0.7	5.4	3.1
CIVIL ENGINEERS	3831.	4415.	5050.	(1985)	2.2	3.4	2.8
ELECTRICAL ENGINEERS	6007.	7448.	8972.	(1985)	3.4	4.8	4.1
MECHANICAL ENGINEERS	5154.	6048.	7038.	(1985)	2.4	3.9	3.2
MINING ENGINEERS	645.	788.	963.	(1985)	2.7	5.5	4.1
NUCLEAR ENGINEERS	33.	98.	177.	(1985)	18.6	18.1	18.3
GEOLOGICAL ENGINEERS	703.	709.	742.	(1985)	-0.4	1.5	0.5
PETROLEUM ENGINEERS	2037.	1964.	2054.	(1974)	-1.0	0.1	-0.5
OTHER ENGINEERS	7612.	8700.	10125.	(1985)	1.6	4.2	2.9
TOTAL ENGINEERS	28091.	32490.	37805.	(1985)	2.0	4.0	3.0
TOTAL DESIGNERS & DRAFTSMEN	7344.	8072.	9002.	(1985)	1.2	2.9	2.1
TOTAL SUPERVISORS & MANAGERS	82441.	94237.	108222.	(1985)	1.9	3.7	2.8
TOTAL OTHER TECHNICAL	23370.	27465.	32488.	(1985)	2.3	4.5	3.3
TOTAL TECHNICAL	141245.	162272.	187513.	(1985)	1.9	3.8	2.9
TOTAL NON-TECH (NON-MANUAL)	23453.	28498.	34812.	(1985)	2.7	5.4	4.0
PIPEFITTERS	12935.	15214.	17726.	(1985)	2.6	3.8	3.2
PIPEFITTER/WELDERS	15150.	16506.	18151.	(1985)	1.0	2.6	1.8
ELECTRICIANS	29718.	35155.	41434.	(1985)	2.4	4.4	3.4
BOILERMAKERS	690.	834.	1072.	(1985)	1.6	7.5	4.5
BOILERMAKER/WELDERS	2918.	3930.	4964.	(1985)	4.9	6.0	5.5
IRON WORKERS	219.	279.	348.	(1985)	3.7	5.7	4.7
CARPENTERS	1706.	2241.	2913.	(1985)	4.0	7.0	5.5
EQUIPMENT OPERATORS	18535.	25320.	32547.	(1985)	5.0	6.5	5.8
OTHER OPERATORS	44088.	52649.	64293.	(1985)	2.2	5.5	3.8
METER READERS	14598.	20174.	26310.	(1985)	5.1	7.0	6.1
UNDERGROUND MINERS	50348.	57775.	67604.	(1985)	1.6	4.4	3.0
WELDERS, UNCLASSIFIED	1347.	1753.	2349.	(1985)	3.2	8.3	5.7
TEAMSTERS & LABORERS	195186.	225688.	260999.	(1985)	2.1	3.8	2.9
OTHER MANUAL	237001.	266692.	296156.	(1985)	1.6	3.4	2.5
TOTAL MANUAL	619470.	718209.	836917.	(1985)	2.1	4.1	3.1

@ INCLUDES REQUIREMENTS FOR ENERGY SUPPLY AND TRANSPORTATION FACILITIES

Figure A-5. Manpower Requirements Table for Bechtel ESPM that much more information is needed with respect to regional supply potentialities by occupational category, as well as information on the drain of skilled U.S. personnel to foreign jobs.[30]

A.2.3. Lawrence Berkeley Laboratory Models. The modeling work at the Lawrence Berkeley Laboratory (LBL) is best described as developmental. This work has been a series of projects employing one general approach, rather than one model applied in several applications. The approach is to apply static linear or quadratic programming, input-output techniques to the study of energy use and the impact of shortages of basic energy inputs on industrial output and employment. One objective of the modeling work has been to explore the extent to which input-output and linear programming can be used to analyze energy problems. This research has been supported by EPRI, ERDA and the FEA. LBL work has emphasized tracing the feedback effects on output and employment of constraints imposed on energy inputs. In some applications, detailed specification of processes in energy conversion and in iron and steel production are modeled within the linear programming construct. The prices which determine such substitutions are those inherent in the LP model--the shadow price allocation mechanism. No other price substitutions are modeled within the I-O tableau, and the implied adjustment system of the LP-10 model is one of "full equilibrium" adjustment, as if all markets were perfectly competitive. The static model is applied to scenarios which consider the effects of shortages for specific future time points, such as 1980 or 1985. While the modeling effort attempts to consider substitution in fuel use, the instantaneous nature of LP price allocations is not of great predictive interest,

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30 Gallagher and Zimmerman [175], pp. 8-5 to 8-9.

since fixed coefficients are assumed everywhere else in the model. Also, no price effects are modeled in the configuration of final demands.

A matrix of coefficients for labor-output requirements, including 40 BLS occupational categories, is appended to the I-O model. However, for projection purposes, the 1972 coefficients are assumed to hold. Consequently, the role of capital formation over time and substitution possibilities is not considered. On the whole, much less attention was paid to developing plausible adjustments of coefficients, or plausible values for constraints on industry capacity or labor input, than was given to developing an LP model for the energy subsectors of the economy. It is not entirely clear why the modelers chose to append the I-O model to LP-process models for key energy-producing and consuming sectors.

One of the more recent LBL exercises is discussed briefly below. This study involves the use of a 97-sector input-output tableau designed for the study of energy and fuel-mix supply effects on the U.S. economy.[31] For electric power generation and the iron and steel industry, further detail was added to the sectoral specification, as the major focus of the study is upon electricity production and industrial consumption. The iron and steel industry is a major industrial consumer of electricity. Generating technologies are explicitly modeled using coal, gas, oil, and combinations thereof, and hydroelectric and nuclear electricity generation are explicitly represented. A detailed analysis was made of the difference between peak load electric power generation and total annual electricity demand requirements, with the production boundary constraint defined in terms of peak load.

The model was used to simulate impacts of energy shortages, as in

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[31]Glassey and Benenson [62] and [63].

crude oil imports or power generating capacity, which are introduced as parametric constraints in the linear programming solution. Constraints are introduced which cover upper limits for domestic industrial output, total labor supply, and peak electric power generation. Lower bounds are set on GNP, which the program attempts to maximize. Balance constraints equating energy demand with domestic production plus imports are applied to the six main energy sectors detailed in the model. Point estimate projections are made for 1975, 1980 and 1985. Final demand vectors and 1972 I-O coefficients were obtained from BLS. Labor-output ratios and occupational data by industry category were also obtained from BLS and apply to 1972. Main outputs of the model are GNP and gross output by sector, employment (total and by occupational category), fuel substitutions in electric utilities and the iron and steel industry, energy outputs in various forms, and shadow prices for energy and steel. These show how prices vary as the energy supply constraint is successively applied in the solution of the model.

The static nature of the model makes it useful for tracing impact effects which might have been plausible around 1972. For projections for 1980 or 1985, the model is less useful. For example, BLS final demand projections for those years are used to describe the allocation of final demand, but those allocations reflect BLS aggregate price assumptions and BLS methods for establishing the bridge between final demand and industrial output sectors. Clearly, even the hypothetical price adjustments implied by the shadow prices in the LP program would imply considerably different configurations for final demand prices, and final demand itself. In short, one of the limitations of this construct is that price behavior is not modeled. This is true also for the substitutions in energy production and use implied by LP shadow price allocations. The LP model treats all energy forms as joint products, and quantities demanded are independent of price prior to the operation of the boundary constraints imposed upon the solution. In the general behavior of the model, increasing the scarcity of a fuel leads first to its decline to the lower bound established by the consumption-production balance constraint. Its use then increases up to the boundary imposed by the import constraint. Then, fuel substitution in the electric utilities and iron and steel sectors takes place up to the point where use of the scarce fuel is reduced to zero or the substitute fuel is used up to production capacity. The nature of the LP solution is thus to alter a shadow price for a scarce factor only after a boundary condition is reached, after which the demand for the next most scarce resource is successively raised until it, too, encounters a boundary constraint, its price rises, and so forth. The final equilibrium maximizes output and selects the least cost combinations of energy supplies that will do so, given initial constraints. One attribute of the LP output combined with the I-O framework is that, with fixed labor output ratios (and upper bounds for labor supply by sector and occupation), labor requirements derived in a simulation reflect only the output patterns. The course of capital formation and productivity growth, by sector, and corresponding relative price changes imply that the static model is highly inadequate as a tool for portraying projected labor requirements.

Lawrence Berkeley Laboratory (LBL) developed a very preliminary regional-occupational manpower model for ERDA as a tool for analyzing manpower constraints on energy industry plant construction and operation. The objective was to see if trained manpower in all required operations will be available in adequate numbers to construct and operate the energy plants implied by consumption forecasts associated with the economy's growth.[32] Because energy

[32]Benenson, et al, [47], p. 2.

impacts on industrial and labor markets have important regional characteristics, the modelers somehow thought it appropriate to specify a great deal of static, sectoral and regional accounting detail in preference to a more aggregate but more behaviorally-oriented modeling approach. In this effort, the model treated two regional sectors (Rocky Mountain states and the rest of the United States), 79 I-O industrial sectors, and 40 occupational categories applying to labor demand and supply. The I-O model utilizes the Harvard Multi-Regional I-O Model (MRIO).[33] The two regions treated are aggregated from I-O tables for 51 states. The 1963 I-O coefficients were adjusted to 1972 for relative price changes.[34] Final demands are estimated according to 1972 constant dollars, for each state, although production sector technology is assumed to be the same in each state as in the national economy. The relation between imports, exports and output in each region is also assumed to follow national patterns. Given the same I-O definitions in all states and regions, differences between state patterns of final demand and gross outputs also define the trade flows as the difference between consumption and production. The labor-output coefficients were developed from the BLS 1970 industry-occupation matrix, updated to 1972. These coefficients are assumed applicable to conditions in 1980, a typical forecast year. Five energy sectors are explicitly considered in the model, with all outputs expressed in terms of BTU's. These sectors are coal, crude petroleum and natural gas, refined petroleum, electric utilities and gas utilities.

In order to impose a linear programming allocation process on industrial choice, and indirectly the demand for various types of labor, con-

[33]Polenske [148].

[34]Benenson, et al, [47], pp. 15-16 and p. 73.

preted as market prices. Thus, as with many static I-O models, there is no acceptable price allocation mechanism working on the adjustment of final demand patterns, industry trade margins, or technical relationships within the industrial sector. This lack of a pricing mechanism is precisely the reason that the constraint of equality between energy production and consumption cannot be imposed within the model while other constraints are operating--there is no concept of scarcity incorporated in the model. Similarly, there is no state level or regional model which describes how labor markets would function by occupation, or how capital would be allocated, which would be of great importance in defining actual regional labor demand.

A.2.4. Project Independence Evaluation System (PIES) Model. The PIES system is a comprehensive energy sector model developed by the Federal Energy Administration. PIES is designed to evaluate mid- to long-term equilibrium conditions in the U.S. energy economy. It is perhaps the most extensive energy model in terms of scope and complexity. The system has been used extensively in analyzing national energy scenarios, such as those presented in the National Energy Outlook. The model seeks to answer questions concerning the level of U.S. oil imports under various world oil price assumptions and assumptions about the supply responsiveness of the U.S. energy sector. The integrating model (PIESIM), numerous supply submodels, and the Regional Demand Forecasting Model (RDFOR) compare the PIES and are described in general terms in a 15-volume FEA series, Project Independence Evaluation System (PIES) Documentation.[36]

The core of PIES is the integrating model (PIESIM) which is a detailed

[36] The most useful general description of the system is found in FEA [59]. The demand model is outlined in FEA [58]. A very good overview of the original modeling effort is given by Hausman [180].

regional description of the U.S. energy economy, wherein production, conversion, transportation, distribution and consumption are interrelated. Although PIESIM ties demand and supply together, most of the structure of the overall PIES model is concerned with energy supply and distribution. Figure A-6 shows the overall structure of the model in much simplified detail. PIESIM brings together the following main components of the domestic energy economy:

1. Fuels demands from the Regional Demand Forecasting Model.
2. Oil and natural gas drilling activity, primary supply, and production from the oil and gas supply models.
3. Coal mine and coal supply from the coal model.
4. Imports of oil and gas, given exogenously, or derived from the International Energy Evaluation System (IEES).
5. Energy supply from nuclear, synthetic, solar, and geothermal technologies, given exogenously.
6. Power conversion in refinery and electric utility activities.
7. Transportation and distribution facilities.

The detailed energy flows modeled with PIESIM are illustrated in Figure A-7. This detail is expanded again by the regional specification of these activities. PIESIM also reconciles differences in regional definitions appropriate to demand and to supply activities in various energy forms.

PIESIM is a static, linear programming model which produces optimum energy supply and equilibrium price configurations for the complex energy sector for 1980, 1985 and 1990. The linear program chooses minimum cost fuel combinations which satisfy demands, and chooses optimum locations for producing basic fuel supplies, and for refining, generating and transporting activities. As an optimization model, it operates according to prices, assumptions about the resource base, technical (input-output relationships) and cost data pertinent to numerous supply activities. It also operates

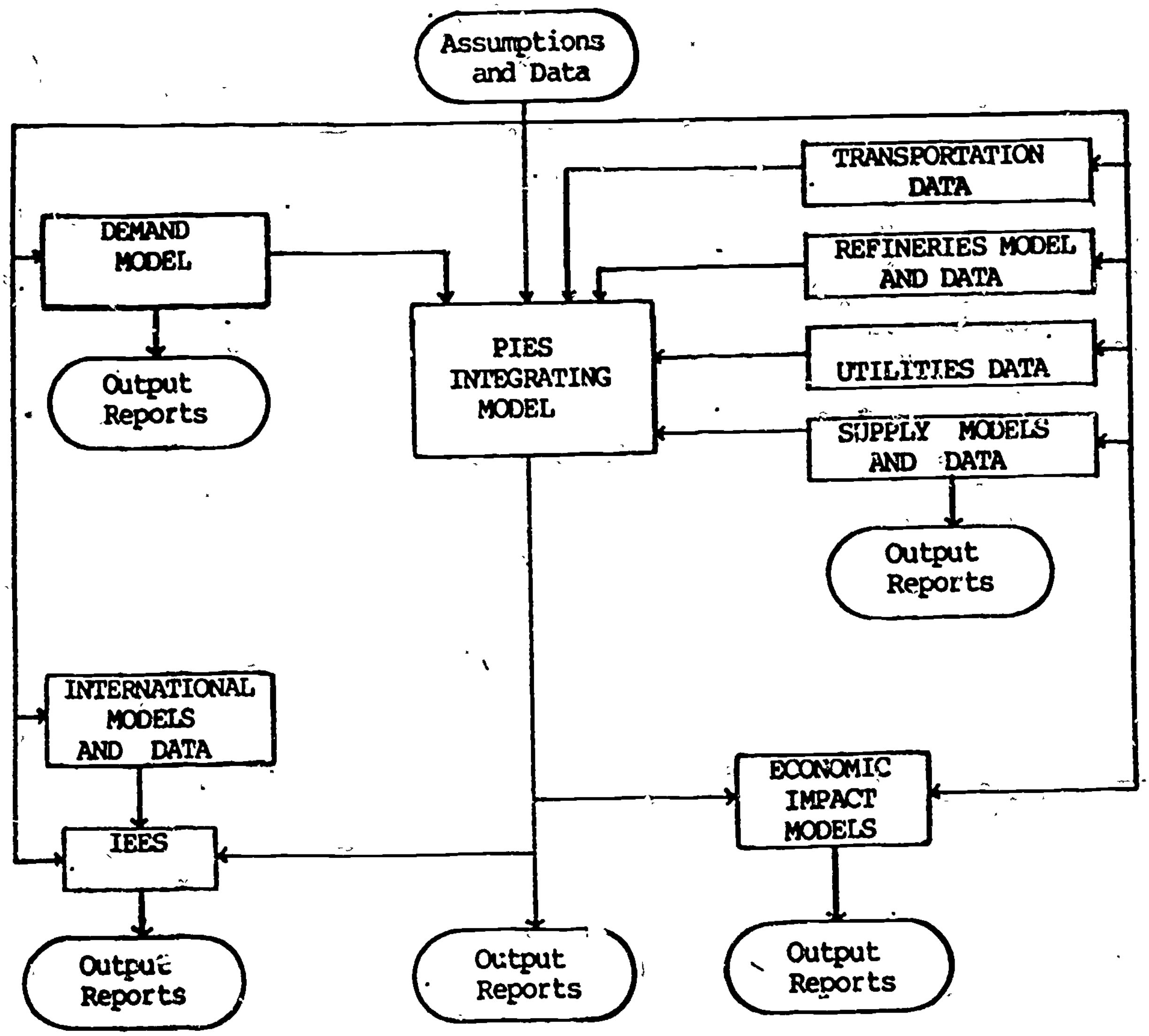

Figure A-6. Overall Structure of the Project Independence Evaluation System

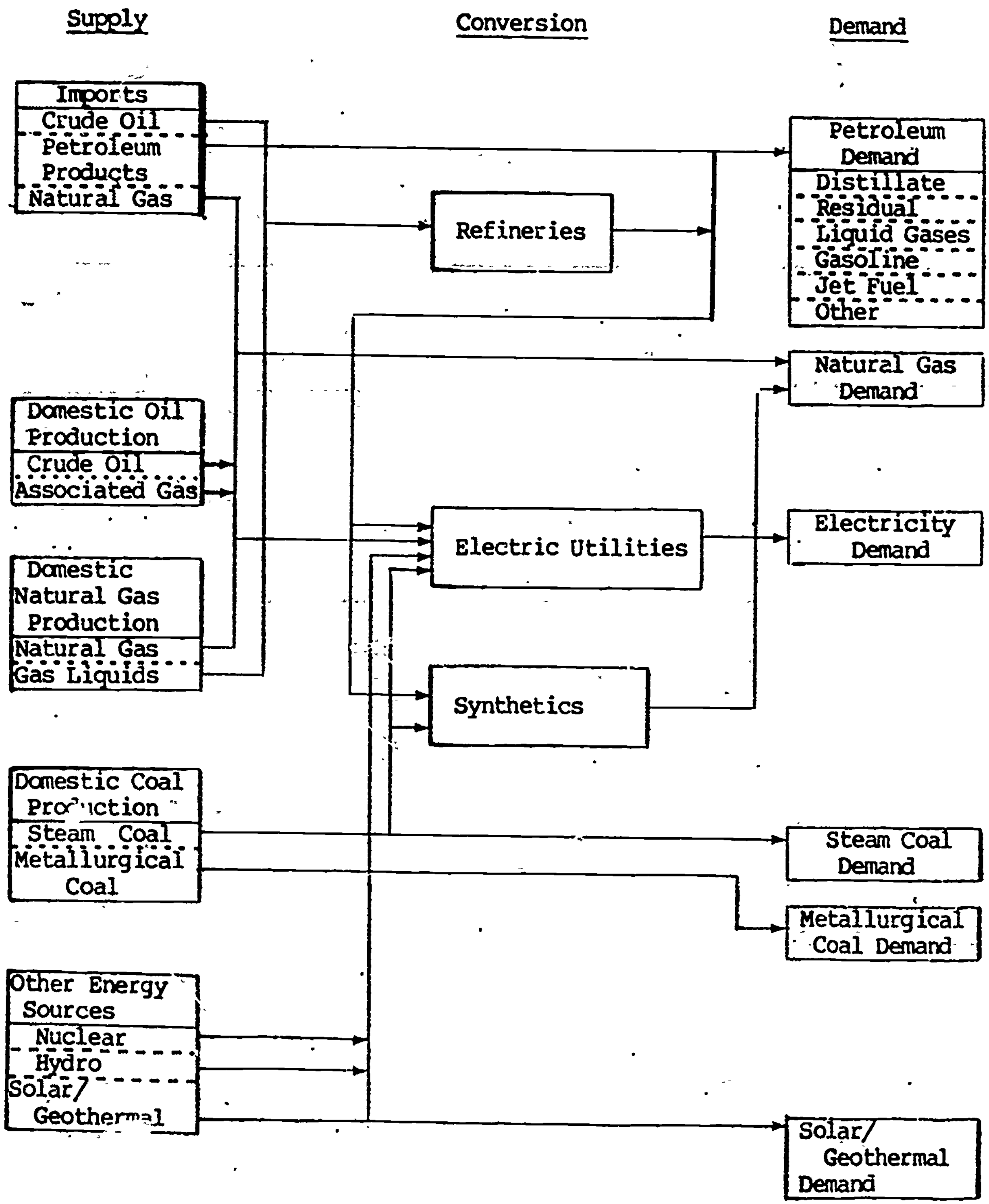

Figure A-7. Flow of Materials in the PIES Integrating Model within the boundaries provided by various capacity and policy constraints and policy-derived market conditions such as price regulations (as for "old" oil, natural gas, oil entitlements, etc.). Tax measures which affect conservation are the main exogenous factors which interfere with a perfectly competitive approximation to market equilibrium implied by the linear programming solution.

In implementing a PIES simulation, exogenous values are given for import prices and availabilities, for conservation, for primary energy supply conditions, for technical and price-tax-cost constraints, and for macroeconomic variables. The macroeconomic variables are produced independently from one of several widely-used models.[37] The main variables here are for GNP, unemployment, population and income (or an activity measure such as value-added or industrial production appropriate to the demand sector in question). These are taken as equilibrium values for 1980, 1985 and 1990. These macro variables are used to drive the demand model. Demand is specified according to four main categories--residential, commercial, transport and industrial consumption.[38] The main features of the demand model are its regionality, its allowance for dynamic adjustments which represent economic costs and inertia associated with converting existing capital stocks in response to sudden energy price changes.

The manner in which fuel demands are specified and integrated into the PIES framework has important implications for the consistency and validity of

[37]DRI long-range forecasts have been typically used for this purpose, for example.

[38]Demands in the transportation sector, for auto and truck gasoline and diesel use, rail diesel use and commercial jet fuel use, are obtained by a separate methodology emphasizing end-use, as interfuel substitution is not a main issue. The auto gasoline demand model is described in Sweeney [118].

resulting projections. As noted above, there are four main categories of demand. Within each of these, total demand is met by one or more substitute fuels such as electricity, natural gas, distillate and residual fuel oil, kerosene, etc. The modeling problem is sizeable, as total demand, component fuel demands and regional characteristics in each of the four sectors must be accounted for. In order to limit the simultaneous demand estimation problem to something more manageable than the 63 equations implied by seven fuels in nine regions, a three-step procedure was devised to simplify the analysis. First, for each of the four major demands, an index of total energy demand is specified as a function of an activity variable (income, value-added, etc.), and the absolute level of a deflated (constant price) fuel price index, also exogenous. Second, estimates of intermediate fuel demands for electricity or petroleum refining are determined (within the PIESIM model). These estimated demands are then subtracted from the total energy demand in each category. The third step is to divide the net total demand for fossil fuels among competing fuels in each of the nine regions of the country. Regional quantity and price values are constrained to add to national totals in each demand category by specification of total quantity and price indexes as log-linear, value-weighted averages of regional prices or quantities. The regional value shares (weights) remain fixed over the entire projection period, a very stringent condition.[39] The regional fuel mix within each demand category is arrived at by using a simple share function, where the ratio of each specific fuel to the total energy index (in each region) is determined by the price of

[39]It may be noted that total energy demands, by region, are calculated by varying the intercept value in regional equations, which are constrained on all other coefficients to national aggregate values (derived from pooled estimation methods). Thus, the adjustment response to prices and incomes is assumed to be homogeneous across all regions, a highly restrictive assumption.

each specific, competing fuel relative to the total energy price index (in each region), and the lagged value of the dependent variable.

Since demand estimates and elasticity calculations entering into the PIESIM integrating model are critical to the equilibrium price and allocation choices made within the system, several results and limitations associated with this set of procedures are worth noting. First, the exogenous aggregate fuel price index developed for each demand category for 1980, 1985 and 1990 is determined by adding an assumed markup to prices of primary energy supplies, and weighting the fuel prices together by 1972 value weights for all years in the projection period. Consistency between these assumed equilibrium prices and the equilibrium prices generated within PIESIM is not guaranteed by the model. Nor is it clear what, if any, consistency exists between these exogenous prices and macroeconomic projections of income or activity, also exogenous to the demand model. Second, exogenous income and activity levels are apportioned to regions according to the 1974 regional income share estimates developed by the Commerce Department (Survey of Current Business, April 1974).[40] Hence, regional income share adjustments which could be expected to accompany regional energy price changes generated within PIESIM are not permitted. Third, the activity variables enter only the overall demand equations for the four main demands, and do not enter directly into the demand equations which determine detailed fuel mix demands for the fossil fuels where fuel shares are related to the own-price relative to the total energy price in each demand category. Thus, regional fossil fuel demands do not vary directly in response to regional differences in income levels. In addition, with only an own-price variable to determine fuel choices, cross-

[40] FEA [59], p. 20.

price elasticities of demand with respect to all other fuels become identical.[41] In combination with the fact that demand elasticities for each major demand's total in each region are constrained to be equal, much of the robustness of the regionality of the specification would appear to be lost. Fourth, the fixed weights or shares determined for regional incomes, demands and prices is a very restrictive assumption, particularly if regional demands, prices, and incomes vary substantially in the projection years from values implied by shares applicable to the early 1970's. Most of these reservations regarding the PIES demand model are known to FEA analysts. However, the operational implications of these factors do not appear to have been empirically evaluated, and documentation regarding the way in which the model was handled to compensate for implausible results related to these deficiencies is not available.[42]

The demand model provides PIESIM with a set of initial quantities, prices and demand elasticities. In a solution iteration to derive equilibrium conditions in the energy sector, PIESIM starts with estimated quantities demanded. These are interfaced with energy supply schedules to determine a marginal supply price (point estimate). Various market conditions, such as price regulations, are permitted to override the initial marginal prices, to give a set of supply prices. Adding in various markups for interim activities generates an estimated set of retail prices. Given the demand elasticities, a new set of quantities demanded are determined.

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[41] Hausman [180], p. 538.

[42] Hausman [180] found, for example, that cross-price elasticities of demand between coal, natural gas and fuel oils had incorrect signs. Hence, fuels appeared to be complements when it is most probable that they are substitutes. The result was that with higher oil prices the demand for natural gas falls—a counterintuitive result. It is not known how later versions of the model were corrected.

Initial and final prices are compared and, if not equal, PIESIM iterates successively until all constraints are satisfied and a set of equilibrium prices is computed which balance supply and demand in all sectors and regions. As noted above, the equilibrium prices determined within PIESIM will not necessarily agree with original point estimate prices entering the demand model. Consistency here is achieved by ex post evaluation.

The main computer output of the PIES model is "Wonder Cookie."[43] The main tables in this output provide the following information:

1. Summaries of national levels of production, consumption, and imports by fuel and sector;
2. Regional details of oil and gas production and distribution, and the allocation of natural gas shortages under price regulation;
3. Regional details of coal production and distribution;
4. Sectoral/regional energy consumption by fuel;
5. Regional refinery fuel consumption;
6. Regional electric utility fuel consumption and generating characteristics;
7. Regional prices, including retail fuel prices in final demand sectors, and wholesale prices in demand regions, utility regions, refinery regions, and oil and gas supply regions.

In its present formulation, the PIES system does not generate any information on employment requirements within the energy sector. Moreover, as there are no feedbacks (except ex post assessments) from the energy economy to the macro economy, aggregate growth, employment and policy remain independent of the energy sector. Current macro models are not well-suited to meaningful integration with the PIES system, because of aggregation and emphasis on income determination rather than on prices and quantities in individual markets stressed in PIES. The PIES model does not appear to be a

[43] FEA [59], p. 60.

useful construct for considering employment questions related to behavior in the energy sector. It is primarily useful as a tool for determining domestic energy demand, short-run supply and, thus, oil import requirements.

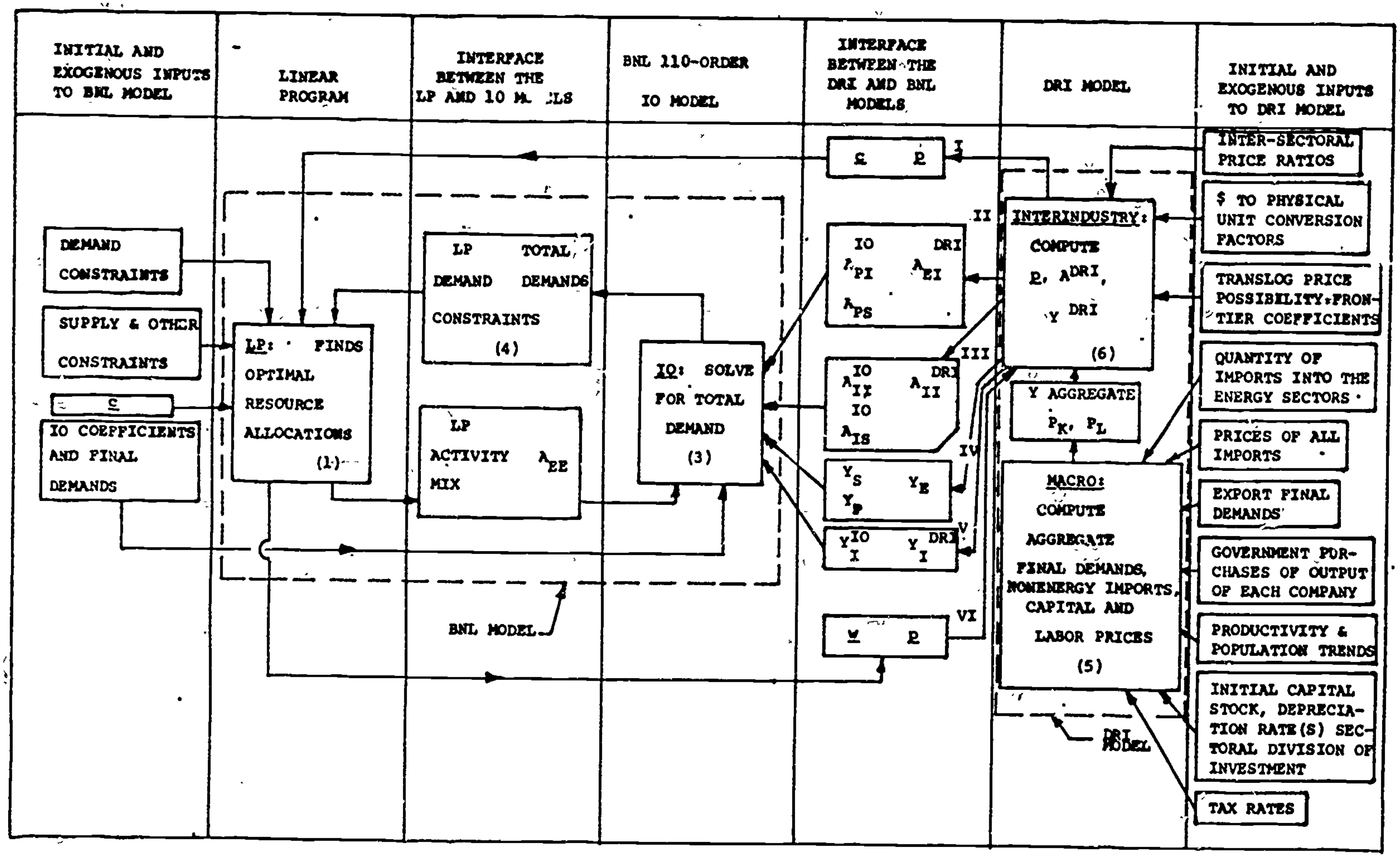
The current status of development of the PIES system is also unknown, as FEA has been absorbed into the new Department of Energy. Changes in the PIES system to rectify some of the deficiencies noted are not known. Available documentation indicates that consideration of some of these problems was underway, particularly in the supply side of the system, but it is not known how, if at all, formal modifications to the system were made.

A.2.5. The Brookhaven Energy Supply Optimization Model (BESOM). The Brookhaven National Laboratory (BNL) modeling effort, under the direction of Kenneth Hoffman and William Marcuse, has been directed at constructing a system for integrating various independent models in order to jointly evaluate economic, technological and environmental factors of importance in the operation of the U.S. energy economy. This work has been sponsored by ERDA, whose principal mandate has been to assess medium- to long-term effects of alternative government policies in the areas of research and development, energy supply and conversion technology development, and measures affecting energy conservation. Given this emphasis on supply and technology, BNL developed the BESOM, which is a linear programming energy supply model. However, since the main emphasis of BNL work concerns the system of linked models, this system will be briefly outlined, and the BESOM model will be discussed in its component role within that system.[44]

[44] The BNL system, including BESOM in various forms, is described in general terms by Behling and others [48], [49], and [50]. Numerous BNL reports to ERDA describe applications of the system to policy issues such as nuclear moratorium legislation [152], and economy impacts of greater use of electricity in comparison with imported oil [197].

The BESOM system is mostly utilized for medium-term projections to 1985, although some runs have been made for the year 2000. In order to interface demand and supply, and also take into account important environmental and technological factors operating at the disaggregated level within the energy sector, a bridge was constructed between the DRI-Hudson-Jorgenson model and the BESOM linear programming model. Although the long-term macro growth model provides a time dimension to the system, the solution of main components is static. Thus, price adjustment reflects equilibrium resource allocation, rather than dynamic price-cost adjustment.

In the BNL system, the H-J model is used to provide the overall configuration of energy demands and provide the entry point for tax policy variables affecting the cost of capital and demand conservation. These aggregate energy demands are then disaggregated into functional demand requirements according to end-use (transportation, space heating, air conditioning, water heating, etc.). This is done in BTU terms for 20 detailed sectors of the 110-sector input-output model. These sectors dovetail precisely with the BESOM linear programming model's sectoral specification. The coefficients for these 20 detailed sectors are not predetermined, but rather are determined by the BESOM solution. The remaining I-O sectors coefficients are taken as an average of the results obtained by BLS and by Almon, and BNL judgment (see Tessmer and Sanborn [81]). Final demand, both for functional energy configurations and for non-energy demands, also rely heavily on BLS and Almon work and on BNL judgments about the composition of detailed energy demands that are consistent with the results of the Hudson-Jorgenson model. The I-O functional energy demands became an input to the BESOM optimization model. As an energy sector linear programming specification, BESOM contains detailed specification of technical-engineering and cost characteristics which



ABBREVIATIONS AND SUBSCRIPTS:

IO : INPUT - OUTPUT
LP : LINEAR PROGRAM(MING)
BNL : BROOKHAVEN NATIONAL LABORATORY
DRI : DATA RESOURCES, INC.

S : ENERGY SUPPLIES (BNL MODEL)
P : ENERGY PRODUCTS (BNL MODEL)
I : INDUSTRIAL SECTORS (NON-ENERGY)
E : ENERGY SECTORS (DRI MODEL)

NOTATION:

$\underline{c}$: LP objective function cost coefficients
$\underline{p}$: price vector in DRI model
$\underline{w}$: shadow prices in LP

IO coefficients and final demands:
(underlined variables are vector quantities)

$$A = \begin{matrix} A_{II} & A_{IE} \\ A_{EI} & A_{EE} \end{matrix} ; \quad Y^{DRI} = \begin{matrix} Y_I \\ Y_E \end{matrix} ; \quad A^{BNL} = \begin{matrix} A_{SS} & A_{SP} & 0 \\ A_{PS} & 0 & A_{PI} \\ A_{IS} & 0 & A_{II} \end{matrix} ; \quad Y^{BNL} = \begin{matrix} Y_S \\ Y_P \\ Y_I \end{matrix}$$

Figure A-8. Integration of DRI and BNL Models

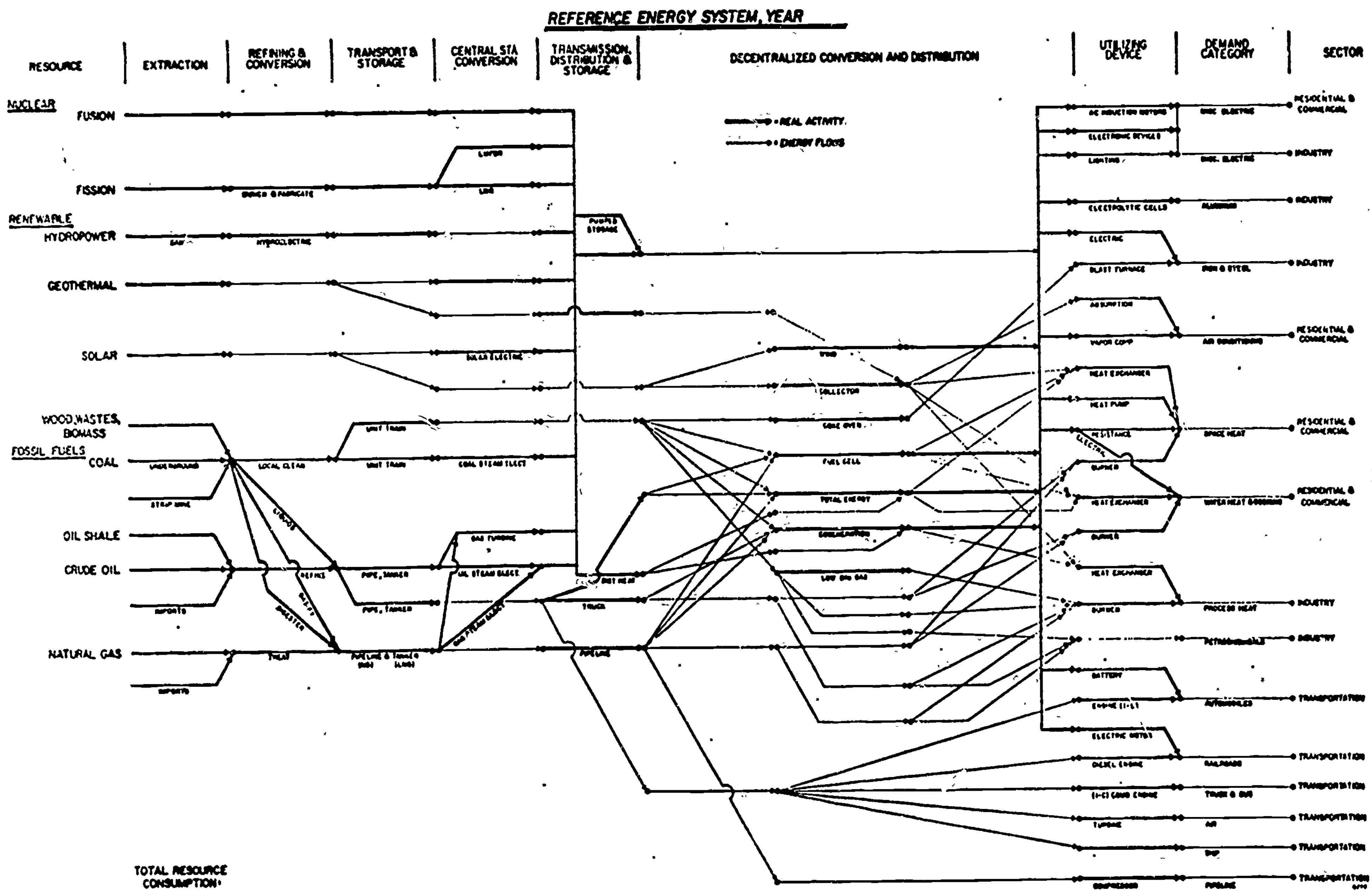


Figure A-9. BESOM: Diagrammatic Representation describe numerous activities in primary energy supply, conversion and distribution within the energy sector (much the same as the detail specified within the integrating model of the PIES system). BESOM also gets as inputs, supply and/or supply price schedules for primary energy inputs (coal, gas, oil), usually supplied by ERDA analysts. Given an upper bound for oil imports, the model endogenously calculates oil imports as a residual, given total energy demand, and domestic supplies. Constraints are set for environmental factors, capacity, peaking and load factors in electricity production, resource depletion, and demand balancing requirements. BESOM solves for a least-cost mix of energy supplies and conversion activity levels provided that supply and demand are in balance given the constraints. Iterative solutions to attain convergence involves the adjustment of the detailed functional demands within the I-O vector. If these cannot be made to converge, total demands are adjusted at the level of the Hudson-Jorgenson model's detail, and a new price configuration is determined at that level. Through successive iteration between these models, an attempt is made to achieve equilibrium in quantities supplied and demanded, and in prices. Oil imports derived in BESOM are also checked against the net exports determined in the Hudson-Jorgenson model.

As noted in the review, a major weakness in the BLS and INFORUM models has to do with the lack of a properly specified price determination mechanism. The data and assumptions underlying the construction of real quantity "bridge tables", or sectoral labor productivities or capital flows, involves a large number of arbitrary factors and introduces inconsistency in the pricing behavior between demand and production. Thus, much of the price consistency achieved in the Hudson-Jorgenson model may be lost in the transition to 110-sector level of detail. Moreover, the I-O model weakens the consistency that should exist between the BESOM linear programs shadow prices and the prices determined by the interindustry macro model. The iterative solution of the system achieves consistency in prices in some unknown way determined by the quality of the I-O disaggregation process.

Attached to the 110-sector I-O model is labor productivity matrix and a capital flows matrix, enabling estimates to be derived for employment on an I-O basis. As with the price analysis, consistency between productivities implied in the aggregate production functions in the macro model, and those implied by labor-output ratios in the I-O model, is not assured by the methodology. Moreover, there is nothing in the model which adjusts these detailed productivity estimates in response to energy sector adjustments except the vague assumption that future productivity growth is likely to be lower, requiring some sort of scalar adjustment of average labor-output relationships from historical trends. A similar sort of economic behavior appears to be embodied in the system in the way in which capital requirements generated in BESOM become reconciled with those in the aggregate model (the capital submodel is run as an option). Apparently, increased supply side investment requirements are satisfied by reducing consumption and rerunning the models with the new demand configuration, rather than being considered to alter the rate of overall real growth in the economy.

A.3. Energy Subsector Models. The models reviewed under this section are those which deal with particular energy subsectors such as natural gas. Typically there are several different models within each subsector classification. These models view the various subsectors in isolation with no feedback effects to the general economy or other energy subsectors. The subsectors covered in this section include: (1) the coal industry, (2) the natural gas industry, (3) electricity demand, (4) gasoline and automobile demand, (5) world energy models, (6) macro econometric models, and (7) single-equation studies. While the last three are not, strictly speaking, energy subsectors, they are included in this section for completeness.

A.3.1. Coal Industry Models. A cornerstone in current official energy policy is the priority being accorded to increasing coal supply. Among the many considerations bearing on expanded coal supply are the development of infrastructure for production, transportation costs, regional manpower availability, mine safety rules, air pollution and environmental reclamation standards.[45] The large influence of government in many aspects of the industry's operation presents policymakers with a greater than usual need for systematic analysis of various economic or environmental trade-offs. For example, the Federal government is the largest single owner of western lands containing large, and as yet uncommitted, low-sulfur coal reserves. While greater use of low-sulfur coal may be desirable from an air-pollution abatement standpoint, various ecological and environmental costs are associated with developing the low-sulfur coal supplies in these wilderness areas. Weighing one environmental goal agiinst another becomes a formidable task because of the externalities involved.[46] Policies which contemplate a large expansion of western coal supply also confront other difficulties. Labor costs (including mine safety costs) are a significant component of the cost-competitiveness of eastern coal, whereas stripmine reclamation costs, transportation costs, and severance taxes are a significant determinant of the cost competitiveness of western coal. An interesting institutional question

[45]Parikh [77], p. 2.

[46]See Macrakis, et al, [188], Chapter III for a discussion of various externalities associated with increased low-sulfur coal production.

in the labor area may arise from the social cost of and labor union resistance to displacement of miners from one region to another which would accompany supply shifts associated with some of the tighter air pollution abatement standards presently being considered.[47]

Coal models are numerous, and generally of two main varieties. First, there are important coal subsector models within large economy-wide energy models (e.g. the PIES model). A second, more important group of coal models, is specifically oriented toward coal supply, transportation and environmental considerations. Because coal reserves, production costs and transportation facilities as well as end-uses vary considerably by geographic region (and by installation), most coal supply models contain a fair amount of regional detail. The pervasiveness of government regulation in so many facets of the industry's operations, and the substitutability of various coal types with each other (and with other energy forms) has made detailed linear programming models more appealing than demand-supply models. This also follows from the fact that it has been difficult to determine the supply function in terms of input prices and factor productivities. Costs vary considerably, installation to installation, even within a region, and even for the same technology.[48] Thus far, most of the analytical effort has been on estimating the delivered price of coal to end-users, taking into account transportation costs, sulfur content (pollution regulations), and production costs measured in very simple terms. Much less emphasis in research work has been given to detailed specification of the cost structure of the industry, and the corresponding factor demand relationships, including manpower requirements. Perhaps more than for

[47] Libbin and Boelje [75], p. 466.

[48] A number of difficulties in this area were the subject of the excellent attempt by Zimmerman in [82] and [83] to estimate a coal cost function for the eastern U.S.

most other energy technologies, labor requirements over the next decade associated with expansion of coal supply are relative unknowns. This follows from a rather questionable understanding of the labor demand function, the relationship between real wages and use of capital-intensive technologies, and the operation of government regulations. The models do suggest, however, that a main factor which will affect future labor demand is the mix of output, between east and west, and between deep mining and strip mining.

In this review, a brief discussion of the Bechtel RESPONS model is given. This model is illustrative of the linear programming coal supply models. Most of these models provide fairly consistent results with respect to assumptions about demand and emissions regulations.[49] RESPONS is also somewhat more detailed than most other models in specifying transportation costs and alternative modes, supplies of alternative fuels, etc. Finally, documentation on the model is more complete.

Main coal models can be categorized into two groups, as follows:

1. Linear programming, regional coal supply models:
   a. Argonne National Laboratory, Asbury [70]; and in Parikh [77]
   b. Bechtel Coal Model--RESPONS [76]
   c. Charles River Associates (for PEPCO)
   d. ICF National Coal Model (for FEA)
   e. Libbin and Boehlje [75]
   f. Oak Ridge National Laboratory
   g. Alan Schottmann's dissertation [80]

2. Regional demand-supply models:
   a. DRI Coal Model[50]
   b. Resource Planning Associates' Model
   c. Coal Sector of the SRI-Gulf Energy Model [56]
   d. Coal Sector of Bechtel's ESPM [54]

[49] Libbin and Boehlje [75], p. 466.

[50] The DRI coal model is currently being developed by Zimmerman. It will integrate the coal demand equations of the existing DRI energy model with a supply model provided by Zimmerman, presumably an extension of his dissertation work.

Most of these models are reviewed by Gordon and Parikh.[51] The SRI-Gulf and Bechtel ESPM models are discussed elsewhere in this review. At present, only the Bechtel ESPM generates estimates of manpower requirements, but this is not a coal sector model, per se. Although none of the programming models attempt to specify input costs in detail, this is conceptually feasible. Hence, manpower requirements associated with coal supply expansion could be attached to the models. The difficulty would be in deriving reliable estimates at the regional level of detail. As Parikh [77] has noted, much more attention is required in developing the data base for the regional supply models, and this is particularly true if the models are to be used with any confidence for projection purposes. Unless reliable point estimates of labor productivity can be made, the efficient output sets determined by the programming optimization process will not be translatable into plausible estimates of labor requirements. Zimmerman's work, cited above, suggests that analysis of productivity trends in this industry is, indeed, a difficult subject, and one which has not been given adequate attention thus far. Lack of more specific information and understanding in this area is no doubt a major reason why none of the programming models has yet been augmented to include detailed specifications for labor requirements.

The Bechtel Corporation developed the Regional Energy System for Planning and Optimization of National Scenarios (RESPONS) model [76] for ERDA. RESPONS is a large-scale planning model, containing parametric data inputs which describe coal supply and distribution activities. In this model, various activities associated with extracting, handling, processing, transporting, converting, distributing and consuming energy are specified according

[51] See Parikh [77] and [78], and R.L. Gordon's survey report on coal models for EPRI [73].

to a set of static, linear relationships. Energy demands are given exogenously, and the model solves for a minimum cost combination of supply and distribution, given capacity and other constraints within the supply system.

The main general categories of activities incorporated in the model include the following:

1. Production and availability of coal and other fossil and non-fossil fuels.

2. Transportation of primary energy forms by various modes--rail, barge, slurry pipeline.

3. Conversion of energy from one form to another, including synthetic liquids, and gas and electric power generation.

4. Distribution, including electrical transmission.

Important constraints on activities which are incorporated in the model pertain to the availability of coal reserves, capacity levels in production, coal-fired power generation, advanced coal conversion (synfuel), sulfur dioxide emission levels in power generation, regional water availability, supplies of alternative energy forms (principally petroleum-based), capacity limits for transportation and distribution, and balance requirements that cause all demands to be satisfied. Exogenous demands are specified in detail for residential, commercial and industrial uses, and for coal-fired electric power generation. Coal supply is in terms of existing mining capacity plus endogenously determined expansion of mining activity. The outputs from the model include quantities of different types of coal, by sulfur and BTU content, by region, and the share of coal output for electric power generation. Activity levels and, implicitly, investment requirements in various activities in the supply chain are also determined. The main use of the model is in determining the number, types and feasible locations of new energy conversion facilities that are required to meet the demands and satisfy environmental considerations.

The regional detail contained in RESPONS is quite extensive. The model output provides detail at 5 and 16 major regional levels, defined by the Petroleum Allocation for Defense (PAD) areas, and/or for 243 Air Quality Control Regions (AQCR).[52] RESPONS has somewhat more detail in terms of regional breaks and transportation modes than most other coal supply models. This is advantageous, as an important aspect of the industry's structure is the wide variation by geographic area in coal types, cost conditions, and distribution possibilities. The advantage of a programming model such as RESPONS is that it permits the user to evaluate the feasibility of alternative assumptions within a methodological framework that imposes efficient choices. Simultaneously, the user of the model is required to make consistent projections of the cost and technological parameters. It is likely that the engineering data upon which many of the technical coefficients are based are considerably more reliable for 10-year projection scenarios, than are the projections of unit costs. The methods for projecting unit costs for various activities do not appear to be wholly satisfactory, either conceptually or statistically. Few attempts are made to specify and estimate traditional forms of cost functions. Thus, coal prices are projected as a function of relative coal qualities. Transportation costs are most commonly stated in relation to distance traveled. Many variable costs and fixed costs for conversion facilities are simple functions of output measures, thereby indicating how costs vary with capacity utilization or scale. These methods omit the important role played by factor prices in the cost functions. This is particularly important as a limitation in the methodology, since for many energy sector activities, marginal costs will be determined by the way in which

[52] Bechtel Corporation [76], pp. 47-51.

factor markets clear, regionally or nationally, for important inputs into the production and distribution activities. Moreover, the behavior of factor prices for inputs to the coal sector are not independent of demand and supply conditions related to activity in non-energy sectors of the economy. As the model's projections of cost items are made, there is no way of knowing if the set of costs projected are consistent with each other, or consistent with demands, supplies and prices elsewhere in the economy.

At the present time, the Bechtel RESPONS model does not derive manpower requirements which would accompany capacity changes for various activities embodied in the model. Neither capital nor manpower availabilities in any way constrain the solution of the model. Capital items are specified in the cost function, but these are not converted into estimates of additions, discards or replacements for facilities. Adding sectors to the model for determining manpower requirements would appear to be feasible, and some of the necessary data may already be available in Bechtel's energy supply planning model. Further research would be needed to determine the possibilities for merging the two data bases and decomposing the cost variables in RESPONS into input prices and quantities.

A.3.2. Natural Gas Industry Models. There are four main models of the natural gas industry: the FPC effort developed initially by Khazzoom [85]; the North-American linear programming analysis by Waverman [91]; the MacAvoy-Pindyck model [87]; and the American Gas Association's Total Energy Resource Analysis (TERA) [84]. Because of the limited direct impact of natural gas on labor and employment problems, only the MacAvoy-Pindyck model will be reviewed in detail. Developed by professors Paul W. MacAvoy and Robert S. Pindyck of the Sloan School of Management, M.I.T., under a grant from the

National Science Foundation, early versions of this model were completed by late 1972. The model has undergone successive modification since that time.[53] The model was designed to evaluate the impact of regulatory policies on the development of natural gas shortages in the 1970's. The demand-supply model formulation stresses prices, gas reserves and production quantities, and final demands. Relationships describing behavior in each of these main activities are specified within a simultaneous econometric model. In application, the model has mainly been used to evaluate the response over time of supply and demand to variations in the regulated wellhead ceiling price for natural gas. Thus, the deviation of prices from market equilibrium values permits estimates to be derived for the size of the shortage in each time period.

The model structure focuses on behavior in two principal markets. One is the field market for gas reserves, which defines the basic supply potential. The second market is the wholesale market for gas production, where production out of reserves, or supply, reflects the interaction of the ceiling prices at wellhead (e.g. pipeline companies selling gas to retail utilities and consumers). Prices at the wholesale level are linked to field prices via a markup relationship, where the markup includes transmission costs and an add-on for profit determined by FPC regulations. The markup items are given exogenously, and reflect variations associated with delivery detailed between 8 production regions and 5 demand regions.

Demand relationships are defined for two consumer groups: residential and commercial sales, and industrial demands. For each demand region, resi-

[53] MacAvoy and Pindyck [87]. See also, Bernanke and Jorgenson [7], for a discussion of the integration of the natural gas model into the Hudson-Jorgenson energy model to study interfuel substitutions in response to natural gas shortages created by price regulation. For a review of the MacAvoy-Pindyck and TERA models, see Neri [78].

dential and commercial demand is determined by the wholesale price of gas, the average price of oil, disposable income, population, and capital expenditures. Industrial demand is determined by the same two price variables, and by manufacturing value-added and/or investment as a proxy for activity levels, also by region.

The supply side of the model also has two main components. Current production or supply out of reserves is a function of reserve levels and the wholesale price of gas. Reserve levels are determined by several endogenous functions which define behavior in the field market. These include explanation of discoveries of gas reserves, both associated with and independent of oil discoveries; extensions and revisions of existing reserves; and the incremental and cumulative number (stock) of wells drilled. Physical drilling activity is exogenous, being a function of lagged drilling revenues, lagged drilling costs, and a risk variable defined as the variance of payoff size for drilling efforts in each production region. The size of new discoveries by well depends positively on the field price (the regulated ceiling price), average total costs, and inversely with respect to the cumulative number of wells drilled in a given region. This latter relationship reflects an attempt to account for the depletion effort, or declining marginal productivity associated with incremental drilling efforts. Extensions and revisions of existing activities are described by lag relationships with past drilling levels, new discovery rates, and the growth of reserves in a given region. New additions, extensions and new discoveries together determine the increment to reserves each year. At the end of each year, reserves are defined by past reserve levels, new additions, current production and inventory changes.

Since the regulated field price is given exogenously for most simulations, and since average total drilling costs are given exogenously, most of the supply side of the model is predetermined, as most other variables are lagged. Similarly, on the demand side with other prices and activity variables given exogenously, and the own-price essentially as an exogenous scalar to the regulated field price, the model determines excess demand, given the lagged structure, and the values assumed for all the exogenous variables in all time periods. Perhaps the most important feature of the model's structure is that the richness of differences in regional behavior, so important in this industry, are taken into account. Multipliers for the model are not evaluated, but alternative simulations are discussed, and the results are plausible. As might be expected, the estimated shortage is very sensitive to how rapidly the ceiling price is permitted to adjust to market prices. Phased deregulation over 4-5 years basically brings supply and demand into balance. The model is rather insensitive to values for exogenous variables, and the results mostly reflect lagged reactions and regional adjustments of demand and supply to changes in the ceiling prices, as these prices are the main variable driving the model.

As presently specified, this model does not incorporate labor requirements in explicit fashion which are associated with drilling and discovery investment activity. However, the unit cost assumptions given exogenously could be decomposed into assumptions about wage rates, labor productivity and thus labor requirements, if the information needed is available with regional detail. Since gas prices have a large effect on investment activity, demand for labor could be examined in relation to wage rate assumptions and price assumptions, through the effect of these on drilling activity. Similarly, labor requirements associated with transmission and distribution activities could be attached to the current model. This could be accomplished if the exogenously specified costs of such activities were decomposed, and labor either endogenously related to activity levels, or expressed as a labor-output ratio multiplied by the activity levels. Again, this amounts to attaching a factor demand specification to part of the supply side of the model. While feasible, it is probably not of great interest, as the capital-intensive nature of much of supply activity does not lead to unusual changes in labor demand that are not easily absorbed in the longer run.

A.3.3. Electricity Demand. The higher energy prices of recent years have promoted a considerable increase in research on electricity demand, with a particular emphasis on conservation potential. Earlier studies were, in general, too aggregated, and failed to capture consumer responses to prices at the margin--prices associated with consumption of the marginal kilowatt-hour of energy usage. Recent studies have tried to tie together household formation, stocks of appliances, prices for appliances, prices for electricity and natural gas, and effects of pricing on the margin and peak-load-seasonal factors in electricity demand and utility pricing structures. Of particular interest is work by the RAND Corporation, and by the Oak Ridge National Laboratory (ORNL) discussed below.

Major deficiencies have existed in the estimation of the price elasticity of demand for electricity for some time, and much of this has been related to three main factors--the use of price data on average rather than marginal prices, the failure to account adequately for peak-load demands, and insufficient attention to seasonal demand variations.[54] The first of these deficiencies is probably the most important. The level of aggregation in the analyses has made it difficult to answer these questions.

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[54] Taylor [110].

Prior to 1970, most electric utilities in the United States enjoyed a period of declining costs provided by the combination of cheap inputs and scale economies resulting from technical advances in power generation and transmission. As a consequence, utilities sought to promote consumption. Rate structures were designed accordingly. Rate setting typically considered recovery of incurred costs, allocation of these costs by class of customer, determination of a fair rate of return on invested capital, and use of average pricing methods to recover the costs.[55] For commercial and industrial customers, this led to the use of "block" pricing. Block prices reflected a fixed, peak-load demand charge (for each class of customer), and a per unit charge for actual kilowatt-hour consumption. Charges were lower for larger usages, with the charges declining in discreet steps, or blocks. This pricing structure permitted the utilities to recover costs under peak-load and initial block charges, and to aggressively sell marginal units of electricity at very low rates, promoting consumption and assuring a high utilization rate of capital stock. The energy problem brought these rate setting practices into question, and prompted intensive study of electricity demand. Interest in energy conservation and financial difficulties facing many utilities have raised interest in marginal pricing and flattening the daily load curve for power generation, practices which have been followed in European countries for a number of years. Revising pricing methods and pricing structures in this industry has important implications not only for demand, but also for capital and input requirements associated with a different configuration of demand.

<u>RAND Corporation Studies</u>. The RAND Corporation work has been carried out under the leadership of Jan Acton and Bridger Mitchell. This work has been

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[55] Mitchell and Acton [108], p. 2.

supported by the Federal Energy Administration, the National Science Foundation, the Los Angeles Department of Water and Power, and the California Energy Resources Conservation and Development Commission. Most of the work evolved from an analysis of electricity rationing in Los Angeles County during the energy crisis. This evaluation led to an intensive analysis of disaggregated data from which new estimates of demand elasticities were derived, along with an evaluation of load factors and seasonality.

Based upon monthly cross-section, time-series data for Los Angeles County, covering the period July 1972-June 1974, electricity demand equations were estimated. A main feature of the data base was that it permitted estimation of marginal prices. Based on marginal pricing behavior, significant negative price elasticities of demand were obtained. From cross-section data, the estimates varied from -0.3 to -0.5. Cross-price effects with respect to the impact of natural gas prices on electricity demand ranged between 0.7 and 0.95. The authors attribute these large cross-price elasticities (larger than the own-price elasticity) to implied adjustments in electrical appliance stocks and intensity of their utilization in response to changes in natural gas prices.[56] The elasticity of demand with respect to real per capital disposable income is estimated to be in the range of 0.4, implying continued growth in electricity demand as the economy grows in real terms over time. An important finding of the demand analysis was that lump-sum components of the declining block rate structure (customer charges and amount of payment above the marginal price in preceding blocks) have a negligible effect on the amount of electricity consumed--which places emphasis on the importance of using marginal prices, not average prices, to determine the price elasticity of

[56] Acton, et al, [93], pp. 36-37 and p. 48.

demand.[57] The large cross-price elasticity for natural gas suggests that substantially higher natural gas prices would promote large increases in the demand for electricity. The elasticity estimates also indicate significant short-run impacts on utility revenues in response to large price increases, and thus the ability to cover large fixed costs, and this in turn suggests a re-examination of the pricing structure to cope with larger-than-historical price changes.

Additional studies by RAND have been performed in the area of peak-load pricing, applying some of the concepts developed by European utilities to electricity demand in California. A study of 18 industrial consuming categories indicated that reductions in electricity used during the peak period permits utilities to supply the same quantity of electricity at off-peak hours more efficiently, therefore lowering the cost per kilowatt-hour supplied. Over the longer term, reductions in electricity use can potentially permit utilities to postpone or eliminate additions to peaking capacity and to achieve greater efficiency from a given mix of generators. The result of this study suggests that, statewide, on an all-industry basis, a reduction from peak-load demand of about 5 percent could be achieved through changes in load management.[58]

<u>Oak Ridge National Laboratory Engineering-Economic Model of Residential Energy Use</u>. The ORNL modeling work, sponsored by ERDA and FEA, has been directed by Eric Hirst. The ORNL model is a complete electricity demand model which is sensitive to major demographic, economic and technological determinants of residential electricity use. The model has been used extensively by

[57] Acton, *et al*, [93], p. 51.

[58] Mitchell, *et al*, [109], pp. 81-82.

FEA and ERDA to evaluate long-run effects of energy conservation programs designed around appliance efficiency standards, housing construction standards, and tax credits for retrofitting existing homes.

The main objective of the model is to calculate electricity consumption over the long run in response to the following main variables:

1. Stocks of occupied housing units and new construction.
2. Equipment ownership per housing unit, by fuel and end-use.
3. Thermal or technological efficiency of equipment and housing units.
4. Average energy requirements for each type of equipment.
5. Other usage factors that reflect household behavior.

Household formation is determined by population (by age group), by real disposable income (exogenous), and by lagged variables. New housing requirements are a function of household formation and retirements from the existing stock of housing units. New units plus existing units match the number of households. The choice of housing type--single-family dwellings, apartments, and mobile homes--is given exogenously. Given the number of housing units of each type, energy use is then determined as a function of prices and incomes. Household energy use is a choice between electricity, natural gas, oil and other fuels, with the prices of these fuels given exogenously from long-run projections of the Brookhaven BESOM model, spanning the 1985-2000 period.

Electricity demand is modeled for each housing type as a function of end-uses. The end-use demands modeled are:

1. Space heating
2. Water heating
3. Refrigeration
4. Food freezing
5. Cooking
6. Air conditioning
7. Lighting
8. Other

The demand submodel estimates elasticities with respect to income, fuel prices, and equipment prices. Each fuel price and income elasticity is decomposed into two effects--an elasticity of equipment ownership, and an elasticity of equipment usage. Equipment ownership is sensitive to fuel prices, equipment prices and income, while usage of equipment (ownership held constant) is made responsive to changes in own-prices of required fuels, and incomes. The detail gives a total of 272 elasticities within the model.

The technology subsector of the model is based upon detailed engineering studies of equipment energy requirements and equipment prices as a function of design characteristics. Projected thermal efficiencies and input-output relationships from this analysis are exogenous inputs into the simulation model which calculates electricity use.

The model outputs can be used to evaluate appliance and thermal standards, alternative fuel price scenarios and financial incentives for retrofits of existing structures. For a scenario composed of these elements, the model generates energy use changes in the residential sector by fuel and end-use over time. In addition, estimates are provided for changes in household energy costs, capital costs for equipment, and costs for upgrading structural thermal integrity.

The actual elasticities used in the simulation model appear to be some combination of results obtained from ORNL work, and other studies.[59] The ORNL demand estimation apparently involves three steps. The first is to derive household demands for three types of energy use, in aggregate--for electricity, for gas, and for oil. From state cross-sectional data for selected years, 1951-1974, elasticities are estimated with respect to the own-price,

[59]Hirst, Cope, Cohn and Hoskins [105], pp. 19-20.

the price of substitutes, real income and climatic variables. Estimated own-price elasticities averaged -1.0 for electricity, -2.1 for natural gas, and -1.3 for oil. The cross-price elasticity of oil with respect to gas averaged 1.8, higher than the own-price elasticity for oil. This anomalous result is attributed to non-availability of natural gas in some states in the cross-section. The income elasticity of demand was estimated at 1.8 for gas, -.1 for electricity and 0.1 for oil, indicating a clear preference for natural gas in high-income states.

To determine how these estimated demands for electricity, gas and oil get divided up by end-uses, a set of logit share functions were estimated using cross-section data for 1970. Fuel choice shares are a function of fuel prices, equipment prices, per capita real income, heating and cooling degree days, and other variables which serve as proxies for equipment demands and usage. The fuel shares are shown to be sensitive to both own-prices and equipment prices, but prices of equipment appear to have a greater influence on the choice of equipment (by fuel type) than do the fuel prices themselves.

The elasticities estimated for the model are considered the weakest part of the overall model structure at this point.[60] For example, both the price and income elasticities for electricity are much larger here than those estimated by RAND. While the RAND estimates pertain only to a very limited sample (Los Angeles), they have the advantage of being based on marginal prices rather than average prices (statewide average prices in the case of ORNL). Work is underway (ORNL [105]) to introduce more regional detail into the analysis, but this amounts to applying the same model structure to more detailed data within the nine census regions. Clearly, more effort is called

[60] Hirst, Cope, Cohn and Hoskins [105], p. 53.

for in dealing with the fundamental demand estimation problems relating to marginal versus average pricing, and with peak-load and seasonality factors.

With respect to employment issues, these studies of electricity demand have several implications. First, to the extent that better demand elasticities are achieved, larger energy sector models which incorporate estimates derived from these studies will be improved. Secondly, to the extent that models such as ORNL illustrate shifts in the demand for appliances, household equipment, etc., they provide a useful means for assessing shifts in consumer demands over time, in response to higher energy prices. If, for example, plausible results for effects on appliance demand can be derived from such models, these can be translated, by simple means, into estimates of employment requirements in the appliance industry.

<u>The MIT Regional Electricity Model (REM)</u>. Under a research grant from the National Science Foundation, Baughman and Joskow [98] developed the REM for the M.I.T. Energy Laboratory. The result of this research is an engineering-econometric simulation model of electricity supply, demand and price regulation. The principal application of the model has been in the analysis of derived demands for commercial nuclear reactors and nuclear fuel cycle requirements (raw uranium and uranium enrichment) for the period 1975-1995. Simulations with the model focus on the impacts of alternative government policies with respect to pollution control standards, reactor licensing procedures, and electricity rate-setting policies. Tax and depreciation policies are entered via their impacts on the cost of capital. Alternative expectations regarding prices of various fuels and construction costs can also be evaluated. Unlike most other electricity demand models, REM's simultaneous determination of supply, demand and price permits important supply or cost-related variables to be incorporated in the price determination process.

This incorporation is important to a realistic determination of economically viable alternatives among supply technologies in satisfying overall demand for electricity.

The main submodel within REM is the supply model. Detailed behavior is specified in each of nine census regions for investment in capacity expansion, power generation, and transmission and distribution activities. Given alternative leadtimes for plant construction (ten years for nuclear, five years for conventional steam, and two and one-half years to reach peaking capacity), and given different planning horizons, the model calculates how much and what mix of plant investments should be undertaken to minimize expected costs. Technical choices are made among eight alternative technologies with hydroelectric capacity given exogenously.[61] Technical considerations and firms' expectations for cost variables are specified exogenously, based on engineering and survey data from the electric utility industry.

The power generating component of the supply model takes into consideration the important linkages between investment in capacity expansion and load dynamics associated with utilization of existing production facilities. In general, since there is an inverse relationship between the degree of capital-intensity of production and operating costs, cost minimization requires detailed consideration of capacity utilization and load dynamics. In selecting among existing plants to satisfy a given load requirement, the model specifies a hierarchy for utilization in which the least cost plants are utilized first. The hierarchy is determined by operating costs only

[61] These alternative technologies are: gas turbine and internal combustion units; coal-fired thermal; natural gas-fired thermal; oil fired thermal; light water uranium reactors; high-temperature gas reactors; plutonium recycle reactors; and liquid metal fast breeder reactors.

(fuel and variable costs), since once a technology is put in place, capital costs are sunk costs, and thus the generating cost profile varies only with variable costs associated with load factors. The model uses extensive industry operating "rules of thumb" and cost information in order to specify these behavioral conditions.

Transmission and distribution is handled very simply, more or less as an accounting system, rather than as a behavioral model. Given the characteristic of the service area (regions) with respect to load patterns, type of consumer (residential, commercial, industrial), and physical conditions (distance, etc.), and given information on operating, maintenance and equipment costs for various activities, total transmission and distribution costs can be computed directly.

The demand model consists of a set of econometric demand equations for electricity, oil, natural gas and coal for the residential and commercial and industrial sectors (with coal only in the industrial sector). These equations are estimated from cross-section data for 49 states for the period 1968-1972. For residential and commercial demand (and similarly for industrial demand), total per capita energy demand is determined by per capita personal income, population density, temperature, and a weighted energy price index in which consumption and end-use efficiencies for various fuels are used as weights. A lagged dependent variable is used to approximate dynamic adjustment considerations. Total energy demand is then "split" between consumption of oil, natural gas and electricity according to a set logit-type share function with respect to price (which permits a convenient means for adding up individual prices to equal the weighted price index), temperature variables, and lagged share variables. The large coefficients for lagged dependent variables, compared to price and temperature variables, suggests that capital stocks associated with particular demand patterns adjust rather slowly, moderating the size of demand responses in the short run which might be implied by radical price changes. These results are generally consistent with those obtained in other studies. In addition, for long-term projections, the use of fixed weights to establish the aggregate weighted energy price index is quite restrictive, as radical price changes can be expected to significantly alter consumption shares over time. Industrial demands are not only split among fuels, but also allocated among states by logit share functions using relative price and population values, and lagged dependent variables. Since the locational function is estimated from cross-section data, the same coefficient (and behavioral response) is made to apply to all states, which is a highly restrictive assumption. The large and significant coefficient for the lagged dependent variable in these locational functions also suggests that supply side factors (rather than demand factors) may be more important than price and population variables. In addition, the negative coefficient shown for the population variable seems implausible. In summary, the demand sector of the model contains many similarities to the demand sector of the FEA-PIES model, with the same type of weaknesses with respect to the validity of regional demand estimates for particular fuels.

The final sector in the model is the price-financial block in which price behavior is modeled after "rules of thumb" applied by state regulatory commissions, embodying concepts such as a "fair rate of return" on capital. Cost data from the supply model plus tax, depreciation and rate of return considerations are used to derive gross revenues. Gross revenues divided by sales gives estimated average prices. Together with prices of alternative fuels and incomes, these average prices determine electricity demand for residential, commercial and industrial components.

REM is presently constructed for use in evaluating investment trade-offs among alternative production technologies for electricity supply, given government policies and prices of alternative fuels. The model is primarily a capital and fuel requirements model. Moreover, capital requirements are defined only broadly in terms of basic technologies, and not in terms of detailed menus of capital requirements and possible trade-offs within a given technology with respect to specific types of capital. Labor requirements are not specified anywhere in the model, and labor costs are embedded in an unknown fashion in the engineering cost estimates for building various types of facilities. Presumably, detailed labor cost components could be determined from engineering studies, and costs decomposed into wage rates and real labor demands. Since both the construction and operation of electricity generating, transmission and distribution facilities is capital-intensive, engineering cost estimates focus primarily on determination of capital costs, as does the model. Hence, embedded estimates of labor and other costs, especially for years beyond 1980, are tentative at best. Regional wage rates and necessary labor supply will have some bearing on the decisions to install a given technology in a particular region. At present, a model like REM abstracts from the detailed market conditions which would determine actual new plant production costs. This is an appropriate modeling decision if key factors determining plant construction are demand, prices of alternative energy sources and government policies, and not factor market conditions related to plant construction as such.

A.3.4. <u>Gasoline and Automobile Models</u>. Gasoline demand, by itself, although quite important to the energy problem as a whole, has little relevance to the employment issue. Oil exploration and refining are highly capital-intensive and employment effects all around are likely to be quite small as a result of decreases in gasoline consumption. However, auto production is a different story. Substantial work has been done over the years on the demand for new cars. None of these earlier studies addressed the question of the effect of fuel costs on new-car demand. Recently, two complete models of the gasoline and automobile demand sector have been produced. The first, done by the Wharton Economic Forecasting Associates for the Federal Highway Administration is described in Schink and Loxley [117]. The other was developed by the FEA by Sweeney [118]. In the Sweeney model, the efficiency (miles per gallon) of a given model year is determined by the real price of gasoline and a weight standardized fuel economy measure provided by the EPA. Next, new-car sales are determined by lagged car stocks, vehicle miles traveled, income, real new-car prices, gas prices per mile, and the unemployment rate. The remaining behavioral relationship is the demand for vehicle miles traveled which is a function of the cost per mile, income, and the unemployment rate. Gasoline dema. can now be computed by summing over all vintages the product of fuel efficiency times vehicle miles. The WEFA automobile demand model relates the difference between desired and actual auto stocks to a time-phased adjustment process. Determinants of the desired stock of autos include demographic variables, income and its distribution, cost of purchasing and operating a new car, and the availability of public transportation. Additional studies of the demand for gasoline include Burright and Enns [111], Chamberlin [112], Houthakker, Verleger and Sheehan [114], Kraft and Rodekohr [115], McGillivray [116], and Verleger and Sheehan [120]. In much the same vein as the electricity demand models, the direct employment impacts of gasoline demand are quite small. The question of the impact of higher gasoline prices on automobile demand (both quantity and size, mileage, etc.) and the consequent implications of that demand for employment in the auto industry, while an interesting question, is too complex for the present models.

A.3.5. World Energy Models. This section of the paper treats two world models in detail. Others have been reviewed elsewhere,[62] and are of less interest to U.S. policymakers since they focus more upon OPEC pricing strategies. There are several types of models which describe particular aspects of world market responses to oil prices and demand-supply conditions. First, there are world oil models, which are consumer nation oriented, such as Kennedy's model (reviewed below). These models determine prices and trade flows given demand and supply conditions. Other models such as that of Kalymon, emphasize the supply price determination process by OPEC, assuming behavior which attempts to maximize the discounted value of depletion of oil reserves over time, given OPEC's own future energy needs and the internal production and marketing structure of the cartel.[63] The World Bank model emphasizes the payments flows from consumer countries to OPEC under alternative pricing strategies of the cartel, which are mainly related to development of alternative energy sources by consumer countries and others.[64] In all of these models, analysis is focused on future world oil prices.

More related to U.S. conditions is work underway at the Federal Reserve Board by Sung Kwack and others. Presently under development are multi-country trade and payments models in which petroleum imports and prices are tied to

[62] Fischer, et al, [122].

[63] Kalymon [125].

[64] Blitzer, et al, [121].

capital flows and balance-of-payments behavior. OPEC portfolio choices related to financial investment of oil dollars can be analyzed in terms of their impact on U.S. capital flows, U.S. deficits (interest payments on Government bonds held by foreigners), and domestic interest rate, profit and investment behavior. In somewhat less detail for financial transactions, the LINK system (reviewed below) can also trace trade flows and macroeconomic effects associated with world oil supply and price developments. Some U.S. macro-energy models, such as the Wharton energy model, are also capable of estimating balance-of-trade effects of world energy sector developments, though without the feedback effects of international trade and price iterations as embodied in the LINK system.

Kennedy World Oil Model. This model was developed to assess the impact of alternative crude oil pricing policies on the international trade of oil and associated products.[65] The model is a static, quadratic programming, multi-regional construct which determines demand, supply and prices in each region, and energy trade flows between regions for a chosen point in time, e.g. 1980. The model has two main blocks--one for the demand and production of refined products, and a second for the derived demand and world trade in crude oil. The model thus has four main sectors: consumption, refining, transportation and crude production in each of 16 world regions. With supply and demand determined exogenously in each region, and with both related to price, the programming solution determines equilibrium prices and trade flows between regions simultaneously.

The model contains a large number of exogenous variables which can be

[65]Kennedy [126]. Support for this work was provided by the Federal Energy Administration and Data Resources Inc. The original model was developed in Kennedy's doctoral dissertation at Harvard University, 1974.

altered by the user for assessment of their impact on energy trade flows and equilibrium prices. Income growth and demand and supply for crude oil are exogenous in each region. Technological and cost factors in the refining model are exogenous also. Although cost factors are assumed the same across regions for a given refining activity, different refinery output mixes produce different capital costs and requirements. In the trade activity, transportation costs, tariffs, quotas, export duties and royalties, etc. are exogenous. Within regions, excise taxes, taxes affecting refinery and supply operations, and environmental restrictions are all exogenous.

The centerpiece of the model is the linear programming process model for the refinery sector. In this model, six separate types of crude oil are transformed into nine final product categories: four types of gasoline, two types of residual fuel oil, kerosene, distillate and naptha. The technical coefficients are estimated for each region, while capital costs per activity are assumed the same, with total capital cost varying according to the output mix. Demands for end products are estimated from pooled data on twelve countries.[66] Income growth for each region is taken as exogenous. The link between final demand prices for products such as gasoline, and refinery level prices is made by a "bridge" or markup which reflects intra-region excise taxes, retail trade margins and transportation costs. Prices and incomes determine the demand for various refined products in each region. Capital costs and the availability of particular forms of crude oil determine the refinery production and capacity structure, and import requirements, given domestic crude supplies. Given the exogenous crude oil supply in each region, that region's derived demand for crude (and exogenously determined demand

[66] Kennedy [126], p. 132.

elasticity for crude), world demand for crude is determined. Given world supply (the price elasticity of supply of crude, new discoveries, or OPEC policies), the world price and trade in crude is determined. Transportation costs also influence world trading patterns and are exogenously introduced.

The model's main use is to measure the impact on world trade and prices of changes in OPEC pricing policies. Changes in assumptions about refinery or transportation sector activity or costs can also be made to simulate effects on trade flows, but these are not of such great interest. One interesting application of the model has been made by Houthakker[67] in which "optimistic" and "pessimistic" demand elasticity values were set exogenously for the main refined products categories, by major region, permitting derivation of import requirements for crude. Given these elasticities, the model can be simulated to determine "optimum" OPEC tariff levels which would maximize their revenues over time. Other assumptions about domestic supply responses of non-OPEC regions can also be introduced separately or in conjunction with elasticity estimates to estimate optimum OPEC pricing strategies. Simila - simulations by Kennedy indicate that an export duty by OPEC of about half the current level, or about $3.50 per barrel on crude is most likely to occur in the long run, given supply response that can be anticipated from currently higher prices.[68] In sum this model, though static, is useful as a tool for determining possible configurations of world and U.S. crude oil prices, which can be used as inputs into other U.S. macro or energy models.

<u>The LINK Models</u>. The LINK system ties together major macroeconomic models for industrial countries, with area blocks for the Middle East and

[67] Houthakker [123].

[68] Kennedy [126], p. 174.

developing countries.[69] Independent econometric models for 16 industrial countries are linked together through a trade matrix, with all prices and quantities determined simultaneously, given exogenous assumptions. The model has recently been used to evaluate the impact of changes in exchange rates, the slowdown in world industrial activity in response to the oil embargo of 1973-74, and to assess the impact of higher oil prices on inflation, and economic growth, worldwide, through 1985.[70] The outputs of the system include all the standard macro-quantities, along with trade flows and prices. The models give estimates for total employment and aggregate unemployment rates.

The models in the LINK system are all typical Keynesian macro demand-oriented specifications, and as such do not offer an optimal structure for introducing supply and cost effects which result from higher oil prices.[71] However, by exogenously altering the prices of exports from the Middle East for SITC categories containing crude oil, or similarly for the SITC categories for raw materials, the impacts of such changes can be approximated. The LINK model has been used to evaluate the impact of $10 per barrel crude oil prices on industrial economies. Giorgio Basevi has applied LINK multipliers to the case of Western Europe, and found that the increase in the price of oil reduced real GNP growth in Western Europe by 2.7-2.9 percent, annually, during 1974-76.[72] The LINK system itself produced decreases of .4 percent, 1.8 per-

[69] Models for main industrial countries included in the system are: Australia, Austria, Belgium, Canada, Finland, France, Germany, Italy, Japan, Netherlands, Sweden, United Kingdom and United States.

[70] Waelbroeck [129].

[71] Klein [128]. See, also, discussion of Macroeconometric Models, A.3.6.

[72] Chapter 3 in Fried and Schultze [174].

cent and 2.5 percent, respectively, in 1974, 1975 and 1976. The difference between the two results reflects the actual values of exogenous variables in the LINK system estimates vis à vis Basevi's linear extrapolations from the multipliers of the model. Basevi notes two important effects on the Western European economies that can be traced using the LINK system. One is the direct effect on the economies' activity. A second is the indirect effect on a country's exports to other countries whose real activity is simultaneously depressed by the higher oil price. Netted out against the latter are increased exports to the Middle East. The LINK simulations also show that prices of all internationally traded primary products would have been 5.1 percent lower than the level forecast as a result of the oil crisis, and that prices of manufactured products in world trade would have been lower by 8.1 percent.

As with domestic macroeconomic models, the LINK system is useful for assessing some of the macroeconomic policy responses appropriate to price and balance-of-trade effects associated with higher oil prices. To the extent that effects of higher oil prices are adequately incorporated in the macroeconomic model, effects of inflation on tax revenues and fiscal drag on economic activity can be assessed. The aggregate models will only show these impacts in broad, general ways, however. For example, by treating only aggregates, shifts in the mix of corporate profits in response to income transfers to domestic energy industries will not be adequately handled. This will occur because the historical structure embodied in profit, investment and other relationships will not property reflect the new activity mix. As a result, actual output, employment, investment, trade and price effects from higher oil prices may deviate considerably from simulated results of the aggregate models.

A.3.6. Macroeconomic Models. Due to their usefulness in forecasting and simulation exercises associated with traditional monetary and fiscal policy questions, macro models continue to find widespread use, and have even been adapted with surprising success to incorporate impacts of essentially supply-determined phenomena, such as food and fuel inflation and energy embargoes.[73] The general method of adapting these systems to supply reductions or supply-induced inflation is to reduce demand and raise prices for final demands to reflect supply-induced real output reductions or output price increases.

Most macro models are Keynesian demand-oriented systems, structured around national income accounting concepts, and the value-added concept of real income and output. The more complete models typically include a production function with factor demands for labor and capital, so that the supply side of the economy is modeled to some extent. In this framework, there are two areas of deficiency in treating supply problems. One is that imports are netted-out against other final demand components, which is consistent with the value-added concept which considers domestic factor incomes, and washes out intermediate transactions. Secondly, as imports of raw materials, such as energy, affect the supply capabilities of the economy, their effects cancel out only in the value-added definition, not in their economic effects on output determination, or in their effects on the price level.

The most extensive efforts to adapt macro models to assess the embargo

[73]Some of the more widely known macroeconomic models include those by Chase Econometrics, Data Resources Inc., Georgia State University, Kent Economic Development Institute, UCLA, University of Michigan, General Electric Corporation, Wharton EFA and the Federal Reserve Board (Washington, D.C. and St. Louis).

impacts of 1973-74 were carried out by Klein [128], with the Wharton and LINK Project macro models. Recognizing the role of energy as an intermediate input, the Wharton annual growth model was run with constraints imposed on the I-O sectors relating to energy. These constraints were translated into real output reductions and higher prices. These output reductions were then used as a basis for making adjustments in final demand components in the Wharton quarterly model. Imports were reduced, reflecting the oil embargo. Consumption was simultaneously reduced to reflect lower consumption of gasoline, motor oil, electricity and residential heating. As far as GNP is concerned, reduced imports and consumption tend to offset each other. To otherwise simulate the effect of the embargo on output, inventory investment was reduced and import prices were raised. On balance, it is the negative inventory change which was used to introduce supply limitations into the demand-oriented macro model.

In the post-embargo period, most macro modelers have been concerned with linking aggregate deflators to the WPI for petroleum products, and linking the WPI, in turn, to the price of crude oil. In the DRI and Chase Econometrics models, this is accomplished with a distributed lag price function between products and crude. The WPI products price then shows up in other price functions which, in turn, determine the GNP deflator price. Import price deflators are likewise modified to reflect the crude oil prices being assumed exogenously in a given simulation. Most of the larger macro models are currently being modified along these lines to introduce energy price effects.[74] The lag structures embodied in the price equations between

[74]The authors were unsuccessful in several attempts to obtain documentation pertaining to such modifications, particularly for proprietary models such as General Electric's MAPCAST.

overall prices and crude prices determine the temporal impact of changing energy prices on the rest of the economy. In using the models, most of the modelers also make ad hoc adjustments in demand components to reflect a priori information about shifts in behavior from historical patterns embodied in the estimation equations. This adjustment procedure is also consistent with the notion of "energy shock" wherein decreases in demand were attributed to the uncertainty generated by the OPEC actions.

By introducing price effects, the models can then be used to evaluate the impact of higher energy prices on the general economy. If the models effectively capture the progressivity of the tax system, the fiscal drag on the economy due to energy-induced inflation can be assessed.[75] Similarly, the interaction of energy prices and effects of monetary policy (thus interest rate behavior) can be examined. In employing the Wharton model for such simulations, for example, Klein has suggested that appropriate adjustment of macroeconomic policies to deal with supply constraints are probably in the direction of tax reductions accompanied by continued monetary restraint, a prescription which is aimed at maintaining real output growth while containing inflation within tolerable bounds.

As indicated above, price considerations associated with energy supply and demand are increasingly taking precedence as the problem to be addressed by macro forecasting modelers. This is appropriate, since short- and intermediate-term availability problems associated with the embargo are becoming less important. An emerging problem which some modelers (mainly at the Federal Reserve Board) are now addressing is the trade account effects, petro dollar flows, and longer-term real transfer effects. If world energy prices

[75] Dernburg [163].

remain high relative to other prices over time, there will be an adverse terms-of-trade effect as between oil consumers and oil producers. A second issue, which has to do with domestic stabilization, will be the petro-dollar flows and the nature of financial and real investments made by OPEC countries.[76] Monetary policy may encounter new difficulty in offsetting short-term capital flows of possibly large magnitude. Foreign investment in the United States over time will earn sizeable interest, and potential monetary flows can affect U.S. balance-of-payments and interest rate behavior. Potential conversion from dollars to other currencies can lead to exchange rate devaluation or higher dollar-denominated oil prices, and otherwise produce a great deal of uncertainty in predicting the outcome of monetary and fiscal policies (effects of deficits) on domestic interest rates, output, and employment. The FED is currently developing models which will enable these financial adjustments to be coupled with the FRB macro model.[77]

A.3.7. Single-Equation Models. In contract to other areas of applied economics, energy economics has witnessed very few single-equation studies. Prior to 1973 most single-equation energy research related to the demand for electricity and, to a lesser extent, the demand for gasoline. Post-1973 electricity demand research, much of which is also single-equation, was discussed in A.3.3. In addition, work in other areas, as for example the gasoline demand discussed above, has also progressed. One of the single most important questions with regard to energy policy is the degree of substitutability among energy inputs and between energy, labor, capital and other

[76] A discussion of some of the potential problems which may arise here is found in Robert Z. Aliber, "Oil and the Money Crunch" in Eppen [166].

[77] We are indebted to Sung Kwack for useful discussion of FED activities in this modeling area.

inputs such as materials. Models such as Hudson-Jorgenson and many others discussed above address this question. If the degree of substitutability is high, then higher energy prices can be easily accommodated. Curiously enough, although production economics is one of the main areas of applied economics, prior to 1973 virtually no work had been done which attempted to measure the degree of substitution between energy and labor and capital. As a matter of fact, virtually no work was done which included energy (in any form) as a factor of production. This exclusion of "intermediate" inputs was condoned on the grounds that the real research issue in production economics was the distribution of income and the degree of returns to scale.[78] Recent work, particularly by Berndt and Wood [134], has made substantial progress in this area. However, a great deal of work remains, much of it relating to data development. Although applicable solely to the manufacturing sector, the Berndt-Wood findings are quite important. Utilizing data developed by Jack Faucett Associates, Berndt and Wood constructed a complete set of cost accounts (prices and quantities for capital, labor, energy and materials (as well as output) for the U.S. manufacturing sector. This data was then used to estimate a constant returns to scale translog cost function. The resulting estimates showed labor and energy to be substitutes, labor and material to be substitutes and labor and capital to be substitutes.[79] The

[78]Technically, the exclusion of intermediate inputs is permissible if one of three conditions is met. The first condition, called Leontief aggregation, requires that all inputs be in fixed proportions, i.e. the elasticity of substitution for each set of inputs is zero. The second condition, called Hicksian aggregation, specifies that inputs can be excluded if their price and the output price are perfectly correlated. The third condition, weak separability, requires that the marginal product of included factors be independent of the marginal product of excluded factors. Berndt and Wood [134] tested for all three conditions and found that none held.

[79]For an interesting discussion of the economic meaning of substitutability in a production function with many inputs, see Hogan [141].

values for these elasticities of substitution (for 1971) were

$$\sigma_{LE} = .68, \quad \sigma_{LM} = -.61 \quad \text{and} \quad \sigma_{RL} = 1.01$$

Furthermore, the results showed that the elasticity of labor demand with respect to energy price is .03, i.e. a 100 percent increase in energy prices will result in a three percent increase in the demand for labor. The elasticities for labor with respect to materials and capital was .37 and -.05 respectively. Additional studies in a similar vein include Denny and Pinto [135], Griffin and Gregory [137] and Pindyck [142].

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