MACRO-LEVEL POLICY ANALYSIS MODELS: A METHODOLOGICAL OVERVIEW

Rodrigo J. Lievano
Robert O. Anderson

ABSTRACT

Mathematical models for analyzing policies designed to alleviate the problems of dwindling domestic supplies of conventional energy resources, the high costs of alternative energy sources, environmental pollution, and threats to national security have proliferated at a prodigious rate in the years since the OPEC oil embargo. Most of these models are posed in a micro-economic framework or treat the energy sector in isolation from the rest of the economy. This relatively reduced scope allows for significant detail in the estimation of first-order effects of policies, but obviously prevents the assessment of their economy-wide effects.

This paper discusses various methods for evaluating the interactions between the energy sector and the economy, and focuses on models which attempt to maintain a high level of micro-economic detail while extending the analysis through macro-economic effects. A model developed at the University of Houston (15, 17) is discussed in detail, and the results from the model for an analysis of the economic effects of energy and environmental policy on the electric power industry are given.

INTRODUCTION

Energy and environmental policy evaluation models developed at the micro-economic level (e.g., 7, 15) have been shown to be effective for simulating the potential effects of such policies on important micro-economic variables and the resulting impact on various sectors of the economy. These models can provide policy-makers with useful insights on the interdependence of policies, the relative impacts between sectors, potential changes in production processes (i.e., changes in inputs, outputs, process technology), and on the behavior of the system in general. This information, though valuable, is insufficient. Policy-makers at the regional or national level are also interested in the potential effects of alternative policies on macro-economic variables such as Gross National Product, employment, and general price levels. Such information can be generated by either designing a policy model at the macro-economic level (at the expense of micro-economic detail), or by appropriately linking micro-economic and macro-economic models.

MODELING APPROACHES

Input-Output (I-O) analysis (12) has become the preferred methodology for macro-economic energy and environmental policy analysis because it provides a straight-forward and comprehensive description of the interrelationships within an economy. Its main limitation is that it provides a static view of an economy, since the technical coefficients relating inputs to outputs in each economic sector are fixed at the levels for the year for which the data for their estimation was compiled. In the absence of methods for estimating changes in these coefficients over time, I-O analysis is valid only for short-term evaluations.

Model designers have devised a variety of methods for overcoming this limitation. Some of these methodologies (e.g., 1, 10) use historical data to estimate functions with which to forecast the technical coefficients over time. This approach is not defensible for use in policy analysis, since historical data is constrained by pre-existing conditions. Changes in inputs, outputs, and technologies induced by new policy actions are likely to differ from historical patterns. A more valid approach is to use Linear Programming models of industrial processes to evaluate the potential responses of cost-conscious management in key industries to changing relative prices of inputs and outputs and to new constraints imposed by regulatory policies. These micro-economic models can be linked to input-output models to provide a consistent method for evaluating the economy-wide effects of alternative policies. The robustness of this approach rests on the capability of LP process models to simulate the decision processes which determine the production configuration of an industry, i.e., the specific mix of inputs and outputs and the technologies used in production. Since these decision processes are ongoing and responsive to changing conditions (prices, technologies, constraints), LP process models provide a sound structural basis for predicting changes in technical I-O coefficients induced by conditions outside the range of historical experience.

THE BROOKHAVEN ENERGY SYSTEM OPTIMIZATION MODEL (BESOM)

This model utilizes a specialized input-output model (3) in which the important energy flows from resource production through end-use are expressed in physical rather than monetary units. The technical coefficients relating inputs to outputs in the energy production and conversion sectors are generated by an LP cost-minimization model (6) which represents the various technologies available to satisfy a given level of energy demands at minimum cost, subject to physical, economic, environmental and other constraints. In this manner, key parameters of the I-O model are made responsive to changing conditions. The solution procedure for the combined models is iterative, and consists of determining total energy outputs through the I-O model, using these values as constraints in the LP model, and calculating new energy production and conversion technical coefficients from the solution to the LP. The iterations continue until the total energy output vector stabilizes (14). The Brookhaven model has been used for a broad range of energy policy analyses, including technology assessment (16), electrification options (4), and oil stockpiling (3).

THE UNIVERSITY OF HOUSTON NSF INDUSTRY STUDIES MODEL

The approach used in this project (17), although conceptually similar to the Brookhaven approach, differs substantially in detail. The Brookhaven LP model is formulated in terms of energy production, conversion and end-use efficiencies for a large set of alternative production, conversion, and end-use technologies. The basic components of the Houston LP model (15), on the other hand, are the energy conversion industries (Petroleum Refining, Chemicals, Electric Power). Each industry is represented by a set of options specifying alternative inputs, processes, and outputs with which to satisfy a given set of demands at minimum cost, subject to physical, economic, environmental, and other constraints. Thus the model focuses on the entirety of industrial processes, and the optimization is based on total costs, not merely energy costs.

The I-O model used in the Houston study is the 484-sector Bureau of Economic Analysis model (U.S. Department of Commerce, 1974), specially aggregated and adapted to correspond to the sectors of the LP model. The procedure for interfacing the two models is iterative, and is developed at the total transactions level (total dollar flows between sectors), rather than at the coefficient level. The procedure consists of calculating total energy outputs through the I-O model, using these as constraints in the LP model, and calculating an entirely new set of transactions for key industry groups from the solution to the LP. These new transactions are then used to calculate a new set of I-O coefficients, which are used in a new solution of the the I-O model, providing a measure of the change in macro-economic activity. The Houston models have been used to analyze the effects of national energy policies on the Texas economy (8), the effects of environmental quality standards on the economy of the Houston-Galveston region (11), and the effects of environmental standards and scarcity of clean fuels for electric power generation, on the U.S. economy (17). The results of this last study are discussed in detail below.

THE ELECTRIC UTILITY INDUSTRY AND THE ECONOMY-1985

As the largest industrial fuel and water use sector and the largest stationary source of air pollutants, the fossil-fuel electric utility industry lies at the intersection of many often conflicting policies designed to alleviate energy and environmental problems. For example, policies designed to lower the level of sulfur dioxide emissions induce or force the industry to convert to cleaner fuels (natural gas, low-sulfur oil). This alternative, however, runs head-on into policies designed to lessen the demand pressure on already scarce supplies of these resources. The alternative left open is to continue to use high-sulfur fuels and control SO_2 emission by installing unproven and expensive control systems. This alternative, in turn, expands the capital investment requirements of an already high capital-intensive industry. The effects of these and other policies, coupled with continued high rates of growth in electricity use, place the industry in an extremely sensitive position. The actions taken by the industry in the next ten years in attempting to balance the many requirements and constraints placed upon it could have significant repercussions on the U.S. economy, particularly through the capital markets.

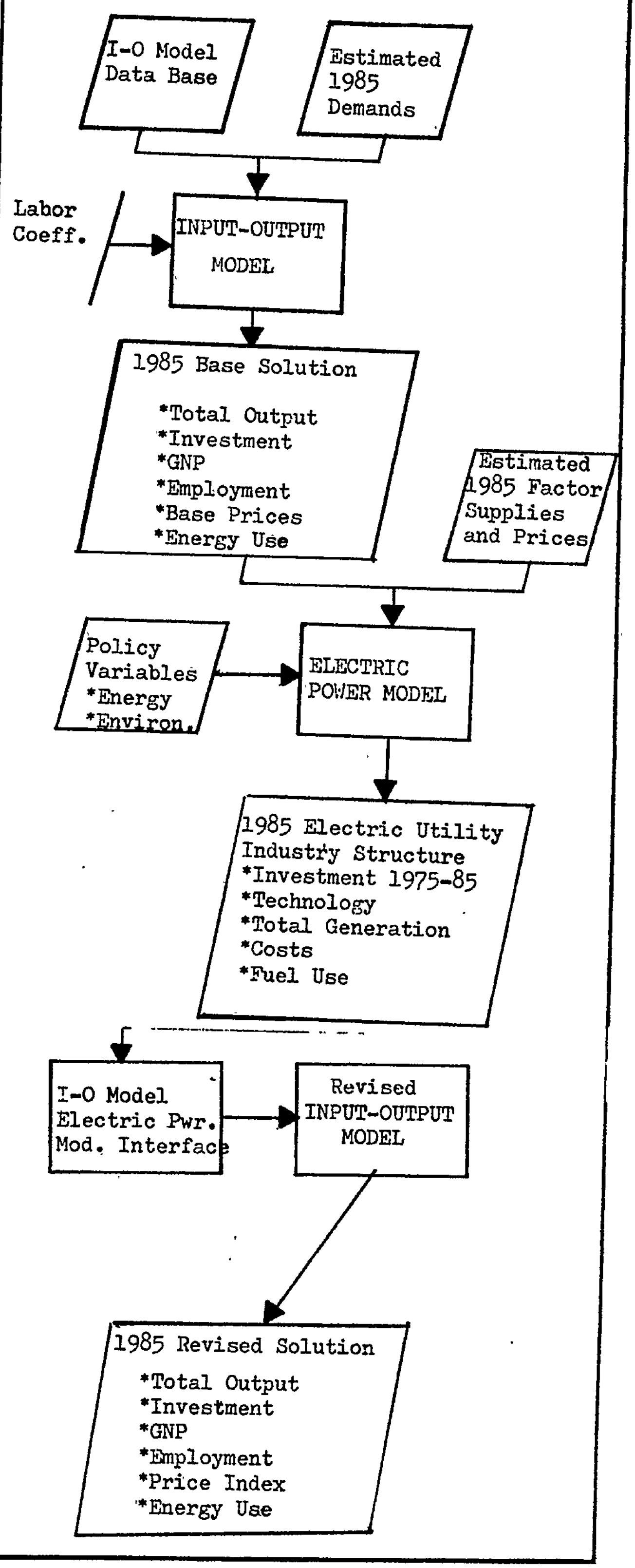
The foregoing considerations motivated the design of a computer-based model with which to simulate the interaction between the fossil-fueled electric power generation industry and the U.S. economy.

MODEL DESIGN

Instead of designing an entirely new model, it was decided to focus on the development of a procedure which would fulfill the desired objective through the linking of previously-existing components. A comprehensive linear programming model had been developed previously in the project (15), and a tape containing the data base with which to construct an Input-Output model was obtained from the U.S. Bureau of Economic Analysis. The procedure developed to link the two models consists of a straight-forward use of the output from one model as input to the other. A solution of the I-O model provides the macro-economic setting specifying total electricity demand, which can be used as a constraint in the electric power model. A solution to the electric power model, in turn, yields investment requirements and, in particular, the production

ILLUSTRATION 1

Procedure Flow-Chart



configuration of the industry. These values can be used to modify the technical (input-output) coefficients of the I-O model, thereby allowing the measurement of the effects of these changes on total output, employment, prices, and total energy use. A flow chart of the procedure is given in Illustration 1.

CASES ANALYZED

Three representative cases were developed for analysis: (1) lax environmental standards; relatively abundant fuel (Base Case); (2) strict environmental standards (cooling towers, zero discharge of total and suspended solids to the water, control of particulates and SO_2 emissions); relatively abundant fuel; (3) strict standards; relatively scarce fuel; no natural gas permitted for new base-load plants. The two latter cases are combined with "Low" and "High" economic growth alternatives. In the "Low" alternative, it is assumed that the economy contracts proportionately with decline in productivity; in the "High" alternative it is assumed that productivity declines are absorbed by increasing the use of resource inputs to maintain a given demand level, that resource supply constraints are elastic (except for fuels), and that an implicit value is placed on the environmental goals being met by increased resource use.

RESULTS

Using Case 1 as a base case, the results show that strict environmental standards on the electric power industry (Case 2) could result in a slight decrease in GNP if the economy is already operating near capacity, and could result in an increase of about .6% otherwise. However, employment increases in any case, by over 1% if the economy is slack. The higher employment rate results from the increased demand for investment in capital (pollution control) facilities. Energy use increases by as much as 2%, reflecting the extra energy needed to operate pollution control facilities, and the extra energy needed indirectly to meet the demands for building these facilities. Prices increase overall by .8% (relative to the real wage); however, the price of power could go up by as much as 22% (see Table 1).

A policy of restricting oil and natural gas to electric power so as to free it for use elsewhere forces electric power to use more pollution control equipment and less efficient production processes. Total energy use increases by between 2 and 3% from Case 2 levels (and by as much as 4.8% from Case 1 levels). Prices are driven substantially higher, and the price of power could increase by as much as 36% from Case 1. Employment does not change substantially from Case 2, while GNP shows more possible contraction, but still well under 1%.

In summary, environmental policies applied to electric power can be expected to cause a substantial rise in overall energy use in the economy and a very substantial rise in electric prices. Effects on employment and GNP are relatively small, but on balance might be slightly stimulative. The effect on the general price

Table 1

Comparison of Economic Indicators in 1985 - Three Cases

	Case 1	Case 2		Case 3	
Prices (factor change from Case 1). . .	-	1.008		1.014	
		Low	High	Low	High
GNP (Millions $1967).	1,401,427	1,398,222	1,409,727	1,391,397	1,410,727
Employment (Millions $1967)	834,267	836,370	843,247	835,163	846,757
Energy Use* (10^{12} BTU).	117,575	118,858	119,838	121,530	123,222

* Includes all petroleum derivatives.

level is somewhat inflationary.

The preceding analysis illustrates how the principles of input-output analysis[1] can be used in conjunction with detailed linear programming models to analyze some important economic effects of various environmental energy policies.

A refinement of the results could be achieved with the interactive use of demand and supply schedules for resources, capital, and labor. Another extension would be to consider several interrelated industries simultaneously, as in the integrated model described in the preceding section, and to analyze their joint effect on the input-output structure of the economy. These same techniques are equally applicable to multiple-sector models. Since these sectors are first made consistent relative to each other by incorporation into a common linear programming model, the accuracy of the results would undoubtedly be enhanced, and their simultaneous impact on the economy would show even more substantial changes than those resulting from electric power alone.

BIBLIOGRAPHY

1. Almon, Clopper, Jr., 1985: Interindustry Forecasts of the American Economy, Lexington Books, Lexington, Mass., 1974.

2. Behling, D. J., "The Effects of Alternative Oil Stockpiling Programs on the U.S. Economy", BNL Report 20048, May, 1975.

3. Behling, D. J., Marcuse, W., Swift, M., and Tessmer, R.G., "A Two-Level Iterative Model for Estimating Inter-Fuel Substitution Effects," Summer Computer Simulation Conference, San Francisco, CA, 1975.

4. Beller, M., Chernavsky, E. A., and Hoffman, K. C., "Interfuel Substitution Study: The Role of Electrification," BNL 19522, Nov. 1974.

5. Brown, L. F. and Zink, L. B., "New Mexico Economic and Demographic Model," Final Report, FRC-351-900-013, Four Corners Regional Commission, U.S. Department of Commerce, August, 1977.

6. Chernavsky, E.A., Brookhaven Energy System Optimization Model," BNL Topical Report 19569, December, 1974.

7. Federal Energy Administration National Energy Outlook, U.S. Government Printing Office, Washington, D.C., February, 1976.

8. Grubb, H. W. and Holloway, M. L., "Simulation of Energy Policies: The Texas Economy," in R. G. Thompson, et al (eds.), op. cit.

9. Hoffman, K. C. and Jorgenson, D. W., "Economic and Technological Models for Evaluation of Energy Policy," U.S. - USSR Conference on Mathematical and Economic Models, Moscow, USSR, June, 1976.

10. Hudson, E. H. and Jorgenson, D. W., "U.S. Energy Policy and Economic Growth, 1975-2000," Bell Journal, Autumn, 1974, pp. 461-514.

11. Klein, R. A. and Young, R. D., "Input-Output Coefficients Implied by an Integrated Process Analysis Model," in R. G. Thompson, et al (eds.), op. cit.

12. Leontieff, Wassily, Input-Output Economics, Oxford University Press, New York, NY, 1966.

13. Lievano, R. J., Ben-David, S., and Brown, L. F., "An Energy Management System for New Mexico," Draft Proposal to the New Mexico Energy Resources Board, March, 1978.

14. Tessmer, R. G., Hoffman, K. C., Marcuse, W., and Behling, D. J., "Coupled Energy System - Economic Models and Strategic Planning," Computers and Operations Research, Vol. 2, No. 3/4, December, 1975.

15. Thompson, R. G., Calloway, J. A., and Nawalanic, L. (eds.), The Cost of Energy and a Clean Environment, Gulf Publishing Co., Houston, Texas, 1978.

16. U.S. Office of Science and Technology, Energy Advisory Panel, "An Assessment of New Options in Energy Research and Development," AET - 9 November, 1973.

17. Young, H. P., Lievano, R. J., "Interfacing Linear Programming and Input-Output Models," in R. G. Thompson, et al (eds.), op. cit.