ENERGY FORECASTING AND SIMULATION MODELS

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ABSTRACT

This paper will present a review of the main methodologies used in constructing energy simulation and forecasting models. The models to be discussed will include:

(1) Econometric Models

(2) Optimizing Models

(3) Structural Models

(4) Time Series Models

A discussion of the various model limitations and problems will also be included in the paper.

I. The Economic-Energy Connection[1]

Up until the early 1970's energy in the form of fossil fuel was abundant and low priced. The problem of how changes in the energy system affected the national economy was given little consideration by economists. There were no models available that could adequately determine how changes in energy costs and availability would affect the national, or for that matter the subnational economy.[2]

In the fall of 1973, OPEC signaled the beginning of the "energy crisis" by cutting off the supply of crude oil from the Middle East and by setting the price of crude oil at a level which most people never dreamed possible. The price of gasoline doubled within a few weeks and gasoline shortages began to appear at the retail level. In a very real sense, the energy crisis exposed the fact that the state of the art of planning in the United States and other parts of the world was abysmal. The federal government neither anticipated the timing nor the depth of the problem.

Ed Carlson, Chairman of United Air Lines, expressed the dilemma of the airline industry as follows in The New York Times: "The airline industry is faced with many problems, but the worst problem of them all is our government is unable to move toward a unified, workable, productive energy policy. It is our greatest concern." The Treasurer of United Air Lines was equally concerned about the recession spawned by the energy crisis and the fact that jet fuel prices at United would increase by 250% in 18 months. Specifically, the Treasurer was troubled by questions of the following type: What will be the impact on UAL's cash flow of a leveling off in air traffic demand combined with substantial increases in jet fuel prices? Should United raise or lower fares, and what changes should be made in the fleet of jet aircraft? Should the airline's fleet of DC-10s and 747s be reduced and replaced by stretched 727s like Eastern and Braniff have done, and what will be the impact on the company's cash situation over the next two years? To be sure, all of these questions could have been answered manually by the accountants and financial analysts at United Air Lines. But every time the Treasurer asked a different "What if?" question, it would literally take man-days to crank out the answers. In 1974 United developed a simple cash forecasting model to facilitate its financial planning process and help the Treasurer answer some of these questions.

In 1974 companies like Babcock and Wilcox, General Electric, and Westinghouse, which produce nuclear power generators, were suddenly confronted with a series of delays and cancellations of orders for nuclear generators. Within a few months electric utilities, which buy nuclear power generators, encountered a sequence of severe problems. First, the prices of natural gas, oil, and coal increased substantially, thus increasing the cost of producing electricity. Second, consumer advocates were pressing for lower electric energy rates. Third, environmentalists expressed concern over the hazards of nuclear power. Fourth, the financial markets from which private utilities obtain funds temporarily ceased to exist. Faced with this array of problems, it was not surprising that electric utilities began hedging their bets on the future since the lead-time to install a nuclear power plant is nearly 15 years. Companies which produce nuclear power generators began asking themselves about the financial consequences of cancellations and delays in orders for nuclear power plants.

During 1974 through 1976, major shortages of natural gas in the textile industry in North and South Carolina were averted only by unusually mild winters. Unfortunately, the projected shortages mateialized in the winter of 1977. What if there is sufficient natural gas to operate the mill for only two shifts a day for three days a week? The dearth of formal planning systems in the textile industry has made it difficult to answer questions of this type. Again, the energy crisis exposed deficiencies in management's ability to plan for the future.

Finally, state and local governments and other institutions encountered similar problems in forecasting the energy crisis and planning for the consequences of energy shortages. The series of energy offices set up in each of the 50 states of the United States proved to be ineffective and powerless in coping with the problem.

But in places like Houston, Texas, one does not refer to the energy crisis but to the energy opportunity. Indeed, many people in the oil and gas business in Houston were not even aware of the 1974-1975 recession. Companies like ARCO, Phillips Petroleum, and Standard Oil of Ohio (SOHIO) stand to reap substantial profits from recently discovered oil field which are now being developed. SOHIO and ARCO are the principals in the development of the North Slope of Alaska. The completion of the Alaskan pipeline is of great importance to each of them. Phillips, on the other hand, has a major interest in the North Sea. In each case, these oil companaies will enjoy significant increases in profits and cash flow as a result of the completion of these projects. What should they do with the profits? First, they might simply increase their dividend payments to their stockholders. Second, they could re-invest their profits in new exploration projects in hopes of finding yet another North Sea or North Slope. Third, they may choose to hedge and put some of their profits into coal, shale oil, or nuclear power. Fourth, they may want to seek new investment alternatives completely removed from energy production. In either case, comprehensive planning will be a necessity if these companies are to exploit the full potential of their opportunties.

As a nation, it is quite obvious that energy consumption and economic prosperity move in concert with each other. Periods of high energy consumption are typically periods of high economic growth and low unemployment. It is equally obvious that periods of falling energy consumption are also periods of increasing unemployment and sagging gross national product. However, it is also true that not all companies or sections of the country are similarly affected by energy induced changes in the economy.

Corporate planning models may make it easier to evaluate the alternatives available to companies, while national and regional energy models could assist government officials in determining energy policy and plans.

The development of computer technology has opened up the use of models so that the user of the model no longer need be the model builder. Of course, there is still the need to understand the model's structure before a user can get meaningful results from a model. With this in mind, the perspective of this paper is more that of the model user, the decision maker, rather than that of the model builder. It is a non-technical outline of the "state-of-the-art" of energy modeling and forecasting with emphasis on the use of the models in corporate strategic planning.

II. Basic Energy Modeling and Forecasting Approaches

A model is a representation of a real world situation. It is an abstraction of reality that is represented by symbols rather than by physical devices. It is used to gain conceptual clarity--to reduce the variety and complexity of the real world to a level that is clearly understandable and easy to specify. The real value of a model is that it can be utilized by a decision maker to improve his understanding of the way in which a system reacts in situations where it is difficult or even impossible to construct or experiment with a real-world situation[3].

The ability to generate short term forecasts for any variable which appears to have a reasonably stable relationship with respect to time is relatively easy to accomplish. A variety of short term, "naive," forecasting tools are available ranging from simple time trends to the Box-Jenkins technique in terms of degree of complexity. Although short term forecasting models have a definite role to play in energy modeling, they have little or no explanatory power and cannot be used for "What if?" analysis.

However, if the user wants to do computer simulation experiments simulating the effects of energy consumption on economic growth or inflation rates, then econometric models are the appropriate analytical tools. Econometric models can also be used to link corporate forecasts to the national and regional economics. But the forecasting accuracy of any econometric model is no better than the accuracy of the policy assumptions and assumptions about the firm's external environment which underlie the model.

Econometric modeling involves a four-step methodology which will be summarized below. These steps include: (1) model specification, (2) parameter estimation, (3) validation, and (4) policy simulation. Given the present state of development of computer software, it is now possible to implement all four of these steps within a modeling system without having to go out of the system to FORTRAN, PL/1, or some other type of subroutines. SIMPLAN and XSIM are among the very few modeling systems which have a fully integrated econometric modeling capability.

Specification. Unfortunately, most econometrics textbooks are concerned only with the question of "Given an econometric model, how do we estimate the parameters of the model?" In other words, the entire question of model specification has been assumed away by most textbooks and university courses on econometrics.

The specification of econometric energy models requires: (1) considerable knowledge of the energy industry, (2) familiarity with econometric and statistical methods, and (3) some knowledge of microeconomics and the theory of markets.

Estimation. Single-equation econometric models can be estimated using ordinary least-squares (OLS) regression techniques. Simultaneous-equation models require the use of techniques like two-stage least-squares (TSLS) or other simultaneous-equation estimators. The application of OLS to simultaneous-equation models may yield biased, inconsistent estimates. Most of the planning and modeling software packages include OLS, but very few of them offer TSLS or other simultaneous-equation estimators.

Validation. The ultimate test of the validity of an econometric model is how well it forecasts the actual behavior of the system it was designed to emulate. This implies solving the model each period for the output variables in terms of given policy variables and external variables as well as lagged values of the output variables generated by the model in preceding time periods. In other words, the model is viewed as a closed loop dynamic system which is driven by a set of starting values for the lagged output variables and given values for the policy and external variables.

Simulation. Finally, once we have specified, estimated, and validated an econometric model we feel we can live with, we are then ready to conduct policy simulations with the model. We simply change the policy variables and external variables and solve for the output variables.

A variety of methodologies and analytic tools are used in energy modeling. Energy models "tend to divide between those that are primarily econometric in formulation, stressing economic considerations and using historical economic time series data, and those that are primarily engineering in orientation, employing optimization procedures and technologigal process descriptions...energy modelers have tended to use the optimization approach to represent the supply side and the econometric approach to represent the demand site."[4]

The following is a brief review of the main methodologies used in energy modeling and forecasting.

(1) Economic Modeling and Forecasting. The econometric method of energy modeling is based on the theorized relationship between a dependent variable such as energy consumption and a number of independent variables that are known or can be estimated such as GNP, population, and prices. The major econometric models are generally composed of a national model tied into specific satellite models of individual energy sectors or regions of the country.

An energy related econometric model can include a number of simultaneous equations that may well be of different types and functional forms. Consequently, accurate and appropriate specification is the key element in the development of a useful econometric forecasting model.

A typical example of the use of econometrics in energy modeling is a total energy consumption model[5]. C_t is total energy consumption at time period t, X_t is the population at time t; Y_t is the gross national product at time t; and P_t is the price per unit of energy at time t. It is reasonable to assume that energy consumption (the dependent variable) is positively related to population and the level of GNP. If population or GNP should increase, we would expect energy consumption to increase. In addition, it's logical to assume that energy consumption would be negatively related to price. Consequently, the modeler might assume a linear relationship with the following specifications

$$C_t = a + bX_t + cY_t - dP_t$$

where a, b, c, and d are the coefficients or parameters which are constant. The coefficient b tells how much total energy consumption (C_t) would increase if population (X_t) were to increase one unit while Y_t (GNP) and P_t (price) are held constant. The coefficient c indicates by how much C_t would increase with a one unit increase in Y_t (GNP) while X_t (population) and P_t (price) are each held constant. The coefficient d tells by how much C_t would decrease with a one unit increase in P_t (price), with Y_t and X_t held constant. The total projected change in energy consumption from the base year (C_t) to the next year (C_t + 1) is the sum of b times the assumed change in X_t, plus c times the assumed change in Y_t, minus d times the assumed change in P_t.

Several energy-economy models are currently being developed utilizing input-output analysis in conjunction with econometric models. The Input-Output Process establishes a relationship between various economic sectors described by input-output coefficients, which indicate the amount of input from one sector required per unit of output of another sector. This type of analysis helps to establish a relationship between energy use and final demand. The Wharton Energy Model combines a large-scale input-output system with a macroeconomic model to produce an overall energy model of about 1,000 equations.[6]

(2) Structural or Building Block Analysis. A non-econometric approach to energy forecasting involves the use of engineering relationships and socio-economic relationships between input variables and energy consumption or demand. A typical example of the building block approach to energy forecasting occurs in the electrical utility industry. Electric utilities try to estimate their future financial requirements through the process of peak load forecasting. The capital requirements of electric utilities are highly dependent on anticipated peak demand for electricity.

An electric utility using the structural approach to load forecasting might use data on new housing starts and data on existing homes multiplied by their expected consumption rates, in conjunction with the development of heating load forecasts from data on the costs of heating with alternative fuels. In addition, the utility might also include in this approach the use of projected appliance saturation data to project residential demand for their product.

In the case of industrial demand forecasting, the load in each industry may be forecasted or projected on the basis of past industrial load growth. These projections are then modified on the basis of planned expansion in the various industries.

This type of forecast uses information derived from recent trends as well as judgments regarding probable or expected changes in these trends and forecasting accordingly.

(3) Optimizing Models. Linear Programming is an optimizing technique which is designed to review a large number of combinations of data and from those select the best combination possible when the selection is affected by a number of restrictions.

An interesting variant of this method of modeling is the PILOT Energy-Economy Model now under development in Stanford's Systems Optimization Laboratory. The model is designed to "measure the impact on the standard of living of various policy decisions, such as the scheduling of various energy technologies to be built and used, pollution abatement equipment to be installed,...the required expansion of the general economy and foreign trade to supply an increasing population with a high standard of living, etc."[7]

The model reflects many assumptions concerning changes in lifestyles, embargoes, feasibility of new technologies, availability of raw materials, the workforce and labor productivity, and numerous assumptions relating to the energy sector. The model is dynamic with linkages through time of raw energy reserves and facilities capacity.

(4) Trend Extrapolation/Time Series Analysis. Time series analysis is a method of forecasting which focuses on the past behavior of the dependent variable with little attention given to an explanation of why the dependent variable behaved as it did. That is to say, where the independent variable shows a historically stable pattern, then the use of time series analysis is a fairly simple to use forecasting method.

In the case where the previous behavior of the dependent variable is characterized by a relatively constant growth rate, the utilization of time series analysis as a forecasting tool is called trending. Trend extrapolation has been a traditional forecasting tool of many electric utilities.

A relatively sophisticated time series model that is used in energy forecasting is the autoregressive model. The Box-Jenkins[8] autoregressive method describes a point in the future as a function of some sequence of observations in the past, rather than applying a simple growth rate to the forecast. Data requirements for the Box-Jenkins are small, basically historical observations of the dependent variable. Once the forecasting model is determined, the production of a forecast simply becomes a matter of plugging-in the output for a particular year, such as total sales of electricity, as an input for the following year's forecast of electricity sales.

If the decision maker's objective is to be accurate, disregarding an understanding of the fundamental energy economic relationships involved, then time series analysis can prove to be a relatively simple and inexpensive method of energy forecasting.

III. Model Limitations and Problems

As energy modeling develops into a usable tool for planning and policy making, its limitations should not be overlooked. There are several general problems in the field of energy modeling that need to be delineated before a model can be used effectively.

The largest problem facing the energy model builder is the availability of adequate data. Large gaps exist in many of the important data series, such as utilization rates for individual appliances, equipment stock characteristics, and energy use by function within industries.

Many times, when data is available it is not in a usable form for introduction into an economic model. For example, available national data on energy requires enormous efforts to distill the information down into usable state or regional data.

Available energy data can also be very inconsistent. It is not unusual to have the same agency publish two different sets of numbers for the same data series, such as gross energy consumption. There are several reasons for this type of problem. The various data-collecting agencies may use different concepts and data collection methods. There are no systematic surveys in the energy field performed by one standardized source as is the case, say, with GNP and the Department of Commerce.

A major instability in the energy data base is that of the accuracy of the measuring tools and sciences. Geological data is an integral part of the energy data base. Estimates of potential and proven reserves are subject to large error factors. Consequently, the development of a more reliable energy data base is dependent to a large extend on advances in geological estimation techniques.

In addition to the data collection problem, there are several other limitations to the current art of energy modeling.[9] First, most energy-economy models utilize equilibrium analysis. However, energy markets are splendid examples of non-free market forces at work. With regulatory intervention and cartelized prices, energy markets generally lack the equilibrating forces associated with a free market. Modelers must make allowances for the institutional aberrations that exist in the energy sector.

Second, energy modeling tends toward an exclusivity of methodology. That is to say, the models generally are either econometric or they are optimization models. Econometric models are prone to ignore institutional realities and technological changes that can affect their results. Optimization models can make allowances for these technological changes, but they fail to reflect the non-optimizing behavior of the real world.

Third, large-scale models are difficult to validate. Problems with cumulative errors, the robustness of functional relationships, structural changes and aggregartion levels have yet to be dealt with. These problems notwithstanding, an adequate validation procedure, if available, would aid in determining the benefits of greater or lesser aggregation.

Since econometric models are gaining greater acceptance in energy forecasting, it is desirable to specify some of the limitations of this particular methodology.[10]

Unlike time series analysis, econometric modeling places the burden of forecasting on the independent variables. It assumes that each of the explanatory variables can and will be independently forecasted. In the case of energy models, this is not an easy task to accomplish. Interdependency of variables is extensive. While the effects of cross impacts can be built into the model's specifications, it is still very difficult to eliminate them completely. At the same time, specification of the model may require the use of proxy variables which may veil the true structural relationships.

An econometric model can be replete with non-explicit, unclear, or dubious assumptions that are essential to the model's results. For instance, a typical econometric model of electrical demand assumes that existing relationships between electricity consumption and various socioeconomic variables will continue in the future. This may or may not be the case. This econometric approach requires aggregation of uses of electricity across all appliances. In the residential sector, for instance, total residential usage is examined rather than separately analyzing the various individual uses such as heating, cooling, cooking, and so on. Consumers owning different types of appliances may respond quite differently to changes in prices and income.

For these reasons, the energy modeler must outline all the assumptions and the limitations of the model. Concomitantly, the model user should proceed with utmost caution in the utilization of energy-economy models.

IV. The Use Of Energy Simulation Models

The utilization of a model after it has been developed and tested depends on the needs and circumstances of the user. Strategic planning, as used here, is "the establishment of objectives and strategies at the highest level of the organization... (that) can be characterized as being long-range in time, critical to survival, and difficult to change once they have been undertaken."[11] In this context it is possible to indicate several steps where models and their results can be incorporated into a multi-scenario planning process.

(1) Use the model(s) to project the "natural" course of the energy-economy system over the time span of your strategic plan.

(2) From the above, isolate the specific features that adversely affect your operation.

(3) Through model simulation, determine alternate patterns of energy development that are acceptable to your firm.

(4) The effects of these patterns can then be introduced into the model, which can generate new forecasts. Based on these simulated alternatives, contingency plans can be formulated which should allow your organization to develop in a more desired direction.

Let me illustrate this point with an example of a one assumption, one scenario approach to planning juxtaposed with an example of the recommended multi-scenario approach.

In 1973, a large regional bank in the United States (the largest in its region) based its 1974 plan on one and only one assumption--the prime rate of interest did not go down in 1974. Instead, due to the oil embargo and the quadrupling of petroleum prices among other things, inflation soared, monetary policy was tightened, and the prime rate reached 12 percent. As a result of one scenario forecasting, that bank became the second largest bank in its region.

On the other hand, the Standard Oil Company of Ohio modeled the effects of alternative completion dates of the Alaskan pipeline on corporate profits and cash flow. Prior to congressional approval of the pipeline, the starting dates and completion dates for the pipeline were unknown and did not lend themselves to analytical projections. Since Standard Oil of Ohio (SOHIO) owned 52 percent of the Alaskan oil field, the completion data for the pipeline was of vital importance. Alternative scenarios were run with the SOHIO model assuming different completion dates for the pipeline and contingency plans were developed for each scenario. In fact, SOHIO's assumed "worst case" turned out to be the true case. Since their simple planning model made it possible to compute the cost of such an eventuality, SOHIO's management was able to construct contingency plans that would obviate the problems inherent in their "worst case" scenario.

In sum, computer models are capable of systematically dealing with large quantities of information. The models provide a means for distilling and storing this information concerning the inter-relationships among various energy and economic variables. The model can examine a specific problem in an internally consistent fashion and provide the planner with the means of altering the values of variables and then assessing the resulting changes.

In effect, energy modeling gives governmental and business planners the tools for assessing the effects of energy options as they apply to a range of economic futures. The overall result is that the model can give the planner not only the primary effects of a given energy scenario, but also secondary reactions and the long-run implications that are essential to strategic planning.

Computer based planning models enable management to examine alternative futures and to look at multiple scenarios. Indeed, it can be argued that computer based planning models make planning possible. Without the ability to look at alternative futures, planning is impossible.

A closing caveat, it is unreasonable to expect an energy-economy model to foretell the future. Econometricians and planners alike must realize that forecasting human behavior is difficult at best. No model can account for unexpected political or social changes. Despite the complexity and completeness of a model, it will produce some apparent inconsistencies and illogical results. Model users must be prepared to alter or modify any model results that run counter to sound practical business experience. In the end, it should be obvious that although models complement strategic planning, they do not replace the use of seasoned judgment in the planning process.

FOOTNOTES

[1] This section is based on a number of examples from a forthcoming book by Thomas H. Naylor entitled Corporate Planning Models to be published by Addison-Wesley Publishing Company, Reading, Massachusetts 01867, in late 1978.

[2] Kazzom, J. Daniel, "Energy-Economic Relationship Explored", EPRI Journal, No. 4, May, 1976, p. 41.

[3] Lee, Colin, Models in Planning: An Introduction to the Use of Quantitative Models in Planning. Oxford: Pergamon Press, 1973, p. 7.

[4] Greenberger, Martin, "Building Bridges Between Model Developers and Users." Modeling Symposium, University of Houston, April, 1977.

[5] Daly, Herman E., "Energy Demand Forecasting: Prediction or Planning?" American Institute of Planning Journal, January, 1976, p. 10.

[6] Klein, Lawrence, "Economy-wide Modeling Capability with Special Reference to Energy." Modeling Symposium, University of Houston, April, 1977.

[7] Dantzig, George B., "Large Scale Optimization with Application to Energy." Modeling Symposium, University of Houston, April, 1977.

[8] Box, G.E.P. and G.M. Jenkins, Time Series Analysis. San Francisco: Holden-Day, Inc., 1970.

[9] For a more detailed analysis of the problems and limitations of energy economy models see, Khazzom, J. D. (ed.), Proceedings of the Workshop on Modeling the Interrelationships Between the Energy Sector and the General Economy. Palo Alto, Calif.: Electric Power Research Institute, 1976.

[10] A good example of the use of econometric modeling in energy demand forecasting including an examination of the advantages and weaknesses of the econometric method can be found in, Northwest Energy Policy Project, Energy Demand Modeling and Forecasting. Portland, Oregon: Mathematical Sciences Northwest, Inc., 1977.

[11] Johnson, Herbert E., "The Contribution of the Economist to Strategic Planning," Business Economics, Vol. IX, No. 3, May, 1974, p. 46.