Energy Vol. 15, No. 3/4, pp. 363–378, 1990
Printed in Great Britain

0360-5442/90 $3.00 + 0.00
Pergamon Press plc

3.5. SIMULATION MODELS

NAZLI CHOUCRI and CHRISTOPHER HEYE

Department of Political Science
Massachusetts Institute of Technology
Cambridge, Massachusetts
U.S.A.

Abstract - This paper summarizes some basic assumptions and procedures for simulation approaches. A brief discussion of system dynamics is presented. A description of the International Petroleum Exchange Model (IPE) developed at MIT is presented. As a simulation model of the world oil market, IPE shows the interactions, adjustments, and behavior of major actors and agents, and of the underlying supply, demand, and price relationships. Illustrations of model results are presented along with comparison of alternative simulation scenarios.

1. INTRODUCTION

A wide range of simulation approaches are available for modeling markets, transactions, and interactions. To be effective for policy purposes, simulation models require specification of criteria to differentiate among options and select among alternatives. Two of the most widely used are system dynamics simulations and econometric-based simulations. This paper addresses some broad features of system dynamics, and then contrasts these with econometrics simulations. We then present the characteristic features and selective behavior of the International Petroleum Exchange Model (IPE), a system dynamics simulation model of the world oil market determining price endogenously.

The objectives of simulation, in general, are to understand the structure of a system, the processes generating behavior, and the outcomes that result from these processes. Policy simulations have the added objective of serving as a tool for purposive or instrumental analysis, i.e., where decisions have to be made and choices among options identified.

2. SYSTEM DYNAMICS SIMULATION

System dynamics is a theory of system structure and consists of a set of tools for identifying, depicting, and analyzing multiloop, nonlinear feedback relationships. Its theoretical foundations are in control theory and systems engineering. The objectives of a system dynamics simulation are as follows:

1. To understand the structure of the system under consideration;

2. To clarify prevailing theories regarding the system in question and provide the basis for the comparison of alternative theories;

3. To identify and resolve differences in assumptions, perspectives, and views regarding the structure or processes under consideration;

4. To isolate sensitive parameters in a model whose modification would affect overall system behavior; and

5. To identify policies that might propel a system toward the desired objectives, or assist in avoiding negative outcomes.

Given the complexities of markets, the salience of nonlinearities, and the difficulties of identifying, measuring, and predicting the future behavior of key variables, system dynamics as a methodology has important potential applications. Many of the problems confronting policy-making involve a host of factors over which actors do not have direct control and whose interactions they do not fully understand. The system dynamics paradigm is particularly well suited for the organization of information, theories, and expectations regarding policy problems, and the simulation algorithms allow for ready investigation of the consequences of alternative policies. Thus, a decision-maker can define the boundaries of his problem, specify in even loose fashion the relationships among key variables, and articulate his expectations regarding their future behavior and observe the consequences of alternative policies.

Assumptions

As a simulation approach to energy modeling, system dynamics is based on the following assumptions:

First, cause and effect are often separate in time and space, suggesting delays in information gathering, policy implementation, and policy impacts.

Second, most key relationships are nonlinear, discontinuous, or have no adequate linear approximation.

Third, policy analyses are at best ones of satisficing, rather than optimizing (as is more conventionally the case with other formal modeling approaches).

Fourth, feedback structures shape behavioral tendencies of a system, depending on the balance of positive and negative loops. The basic structure of a feedback loop is "a closed path connecting in sequence a decision that controls action, and the level of the system, and information about the level of the system, the latter returning to the decision-making point" (Forrester, 1968, pp. 1-7, and 1971). Boundary definition is a necessary prerequisite for modeling.

Fifth, the model is based on specification of functional relationships in a feedback system and not estimation of stochastic relationships. Emphasis is on interlocking feedback with non-linear relations in a system of differential equations rather than (1) best fit criteria; (2) simultaneous solutions of algebraic equations; or (3) optimization of key parameters.[1]

Sixth, simulation is for purposes of conditional analysis, not point prediction. Policy modeling involves simulation of system behavior over time. Policy testing identifies impacts of interventions in system behavior.

[1] There are no methodological reasons why stochastic analysis cannot be undertaken within a system dynamics paradigm or, alternatively, why the parameters of a system dynamics model cannot be estimated from empirical data.

Procedure

A typical system dynamics simulation design involves the following steps:

- Define the problems to be investigated;

- Specify system boundary (delineating endogenous, exogenous, and excluded variables and relationships);

- Identify the reference mode of the system, i.e., the behavior to model and reproduce initially as the first formal representation of the problem at hand;

- Formulate the causal loop diagram representing the feedback structure of the system;

- Formulate the computer flow diagram, an unambiguous graphical specification of the system structure;

- Write the equations;

- Examine the simulation output, noting the model behavior for changes in the structure or in the parameters and undertaking systematic experiments with alternative policy;

- Make policy recommendations based on the results of the sensitivity runs.

Simulation language

The major elements of the simulation language are: (1) levels, which are the state variables in the system and the major structural determinants; (2) rates, which control the fluctuations in the state variables; and (3) auxiliaries, which help define the rates. The key mathematical tool is integration, through which a quantity (level) at any given moment is related to the rate of change of that quantity over time. Rates represent "decision," and levels are the accumulation of all past decisions. In reality, rates are action streams that may be determined by conscious human intervention (e.g., all policies enter the system as rate changes), but may also be determined by structural factors in the system. Auxiliary variables are expansions of the rate equations to assist understanding of the relationship between levels and rates. Auxiliaries and rates may change rapidly; levels change more slowly.[2]

To write the equations for a system dymanics simulation, the modeling language includes: delays, table functions, and constants. Delays represent material lags of material flows in the system and lags in flows. Delays may enhance system stability since they can dampen the effect of an exogenous "shock." Table functions are the functional relationships between two variables as a way of incorporating nonlinear relationships. They are depicted as graphical representations of bivariate relations, and the shape of the graph provides the information necessary for specifying the value of a variable at any given moment.

Two important graphic tools of system dynamics -- the causal loop and the flow chart -- serve as important aids to theoretical formulation and to computation. The causal loop (see example in Figure 1 below) is designed to articulate the theoretical linkages of the structure, process, and outcomes in the system modeled. The flow chart is an explicit representation of the major elements of the simulation language utilized (see example in Figure 3 below). The

---

[2] The computer language for system dynamics is known as DYNAMO. A simplified version of the language developed for personal computers is known as STELLA. A version of DYNAMO is also available for personal computers.

computer equations can therefore be derived explicitly from the flow chart (by specifying the required parameter inputs and values of functional relationships).

In Section 4 below we present the theoretical framework, structure, processes, and outcomes of a major system dynamics simulation of the world oil market. The detailed description is designed to help the reader appreciate the characteristics of system dynamics, its usefulness for policy purposes, and the advantages of specifying interlocking feedback relations in an intertemporal framework.

3. COMPARISON OF METHODS: ECONOMETRICS AND SYSTEM DYNAMICS

This comparison involves key generic issues at the base of all simulation techniques:

System boundary

Econometric (estimation and simulation) models are open systems, including many factors that are, relative to the time horizon under consideration, not determined by the system modeled. Exogenous variables are needed to estimate the parameters of the model, and there are specific assumptions about the nature of these exogenous variables, and restrictions on their use. By contrast, a system dynamics simulation seeks to represent a closed system and generate reasonable system behavior without recourse to exogenous variables. It is assumed that if all the key relationships are included in the feedback structure, then the behavior modeled will be adequately simulated.

Stochastic factors

Econometric models assume that a simulation (or a forecast) is not meaningful unless accompanied by a statement regarding level of uncertainty. An econometric model makes use of information contained in the level of uncertainty and in the distribution of residuals. By contrast, system dynamics assumes that random factors are not strong enough to determine system behavior.

Validation

Econometrics adopts a statistical perspective on validation independent of the purposes of the analyst. For system dynamics validation is defined not by external criteria but by the extent to which the model replicates historical behavior and is useful in decision-making.

Uses of data

Econometric models require data to estimate the parameters and evaluate the validity of the model based on statistical requirements and constraints. Data issues are not as central in system dynamics simulation as in econometrics. System dynamics emphasizes specifying functional relations among variables rather than identifying their statistical relationship.

Reference mode

System dynamics simulation defines the system behavior in equilibrium as its basic reference. Alternative simulations are then compared with the reference or base case. Econometrics simulation based on parameters estimated empirically are used as the base case.

Time frame

System dynamics simulations generally adopt a long-range perspective. Econometrics conventionally focuses on the shorter range, since the parameters estimated from empirical data are viewed as valid only over the data base period. (The algorithims of system dynamics can adapt to any time perspective with any time interval.)

Feedback

Feedback relations are built into system dynamics simulations by assumption, algorithm, and functional specification. Econometric models are generally less dynamic and less prone to feedback specifications, due partly to the nature of the algorithms, and partly to established practices in the field.

On balance, each of these issues is of importance for policy (or engineering-economic) modeling. The choice of simulation approach should ultimately be dictated by the objectives of the analyst. The following section shows the structure and behavior of a system dynamics simulation model of the world petroleum market.

4. INTERNATIONAL PETROLEUM EXCHANGE MODEL (IPE)

The International Petroleum Exchange Model (IPE) was developed at MIT in order to analyze the behavior and interaction of structure, processes, and actors in the world oil market.[3] The IPE model provides an integrated view of the market and key actors to ensure (and enforce) internal consistency as planners or analysts engage in assessments or forecasts of the world oil market. The first version was completed by 1980.[4] The model has subsequently been respecified and disaggregated on both the "demand" and "supply" sides.[5]

As a simulation model IPE focuses on price determination and its worldwide effects. The parties in the exchange are aggregate buyers (the oil-consuming and importing countries of the OECD), aggregate sellers (the oil-exporting countries of the Gulf region in the Middle East), and international managers (the major oil companies). Non-Gulf producers are assumed to play a role in market equilibration in the short run.[6]

The model is based on key equations that represent dynamic behavior and a set of accounting equations that monitor the effects of this behavior. The core features are demand, supply, and price relationships. The price of oil (anchored to the world prices) is endogenous, computed as a function of actual capacity utilization, desired capacity utilization, and costs, which are related to the proven reserve decline rate.

[3] The focus of this summary is on the demand side; however, the IPE model is of the entire market, and the supply side (which is not described at any length here) is specified in considerably greater detail than the demand side.

[4] For a rationale, description, and illustration of the early, complete version, see Choucri (1981).

[5] An early version of the disaggregation was developed as part of a Stanford University exercise at the Energy Modeling Forum. IPE model re-specifications have involved a number of researchers at MIT. Foremost include David Scott Ross, Brian Pollins, Michael Lynch, and, in the 1987 version, Christopher Heye. Michael Lynch was instrumental in the re-specifications of the model for the EMF6 exercise. For results, see "World Oil," EMF Report #6, Vol. 2, 1982.

[6] The model is initialized at 1970 values -- to test for robustness of behavior over a known set of values from 1970-1980 -- and computations are made to 2020. This has helped develop confidence in the analytical structure, as the price changes of the 1970s decade were ill-simulated. The aggregate actors are disaggregated into individual groups and/or states in recent versions of the IPE model.

Price changes affect both the quantity demanded and the amount supplied. In turn, supply and demand adjust to price. There are time lags involved on both sides. On the supply side there are the lags associated with investment delays. In the short run demand adjusts to price, and supply from the Gulf is relatively unresponsive. Non-Gulf supplies adjust to meet demand at the prevailing price. Over the longer run both supply and demand adjust to price and in turn influence the final determination of price.

Table 1 presents a simplified description of the IPE model, for descriptive purposes only rather than to depict the precise relationships. The left-hand variables are endogenous, as are some of the right-hand variables. Once quantities supplied and demanded are generated -- at a particular price -- consumer oil imports, producer investments and imports of goods and services, and profits from oil sales and investments in the oil industry are computed.[7] Figure 1 shows, in simplified form, key functional relationships.

Demand

Quantity demand is modeled as a dynamic process, adjusting to prices, to substitutes, and indirectly to income. Total demand is a sum of demand of (i) buyers and (ii) sellers. In the case of buyers, the oil consuming countries of the West, demand is a function of forecasted OECD demand, adjusted by substitute availability, domestic oil production, and price. The OECD calculations are themselves based on income assumptions and expected price.

The effect of energy substitutes upon demand is thus: we compare the oil price with the projected substitute price at that point in time; substitute availability is determined by the price of substitute energies in any given year. The higher the price of oil, the greater the percentage of oil demand covered by substitutes. Imports demand is computed residually, as the difference between demand and domestic production.

For demand of the sellers, the oil-exporting countries, regression estimates have been obtained based on the impact of population and capital stock on oil consumption. Estimates were derived from pooling cross-sectional and longitudinal data for key Gulf countries.

Supply

Supply is stipulated as (i) Gulf production; (ii) production in consumer countries; and (iii) non-Gulf LDC production. The entire production process in the Gulf is modeled explicitly, taking into account physical conditions, technological factors of exploration and development, and economic ones of costs and price.[8] Domestic supply in the consumer countries is briefer, but takes into account price and depletion.

[7]This specification originates with the initial versions of the model when written in the early 1970s, namely, representing interaction and interdependence among major actors (and agents) in the oil market.

[8] The model specifies the production process as described in Adelman (1972).

Table 1. Simplified analytical representation of the IPE model.

	Key equations	Variables
Supply	$TS = S_p + S_c + S_R$	TS = total supply
	$S_p = f(PC, R)$	S_p = producer supply from Gulf
	$S_c = f(\hat{S}, P, DR)$	S_c = consumer supply
	$S_R = TD - S_p - S_c$	PC = production capacity
		R = reserves
		$\hat{S}$ = base OECD series
		P = price
		DR = decline rate
		S_R = output of residual sellers, inventory changes, etc.
Demand	$TD = D_c + D_p$	TD = demand
	$D_c = f(\hat{D}, P, E)$	D_c = consumer demand
	$D_p = f(Pop, K)$	D_p = producer demand
		$\hat{D}$ = Base OECD series
		E = alternative energy sources
		Pop = producer population
		K = producer capital stock
Price	$P = T + C + MK$	T = tax rate
		C = cost
		MK = corporate markup
Markup	$MK = f(MK_0, PCU, DR, \Delta COMD)$	
		MK_0 = base markup
		PCU = production capacity utilization
		$\Delta COMD$ = change in consumer import demand
Consumer import demand	$COMD = D_c - S_c$	
Market clearing	$S_R = COMD + D_p - S_p$	

Source: Choucri (1981: 25).

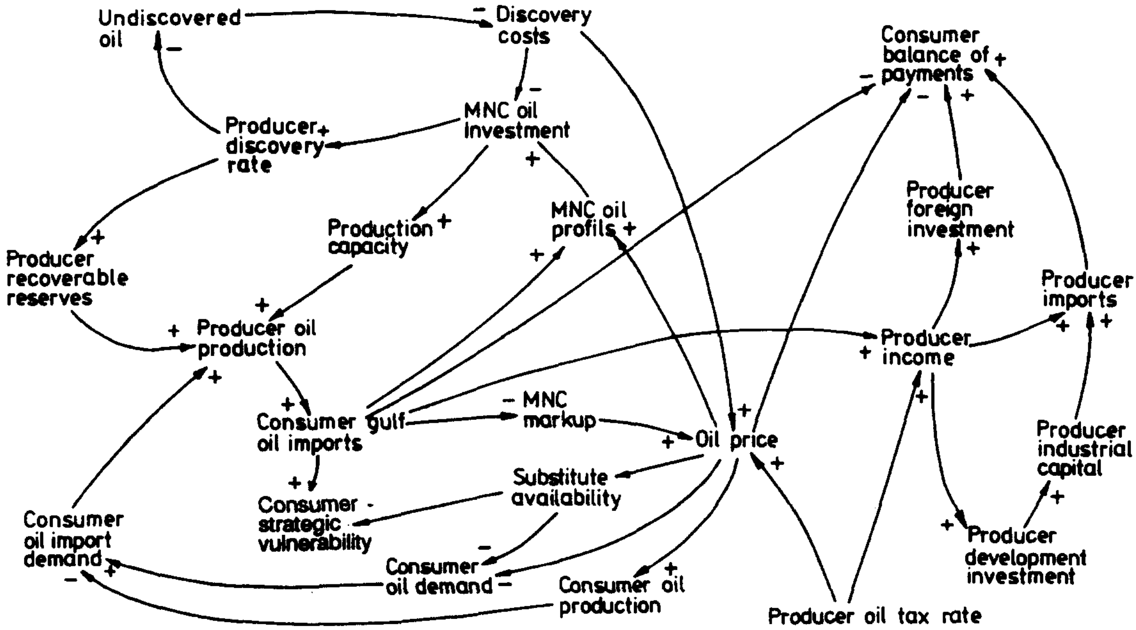

Figure 1. Simplified Model Overview of Major Causal Relations.

Source: Nazli Choucri with David Scott Ross. International Energy Futures: Petroleum Prices, Power, and Payments. Cambridge, Massachusetts: The MIT Press, 1981, p. 30).

Production in oil-exporting countries is affected by demand, given known reserves and production capacity. While reserves of oil in the ground are in producer countries, investments in exploration and development are undertaken by oil companies. Effective exploration investments determine the oil discovery rate that transforms undiscovered oil (initialized at 500 billion barrels for the Gulf fields) into recoverable oil.[9] Changes in recoverable oil-in-place in producer countries varies inversely and non-linearly with output. Investments in development and production costs determine production capacity. The ratio of production to production capacity sets the amount of capacity utilized.

Supply from domestic sources in consumer countries draws on base OECD projections adjusted by price and the rate of depletion. Supply elasticity, indicating the responsiveness of quantities offered for sale to a change in price, is a long-run coefficient set at 0.3. In the short term, of course, supply is relatively inelastic. (The current version of the model specifies both a long-term and a short-term price elasticity.)

Supply from non-Gulf sources is modeled in the same way as consumer oil production, i.e., as responsive to price and to reserves. Non-Gulf suppliers clear the market at each period.

[9] The precision of this estimate is not critical to the model behavior or output generation. It serves only to "anchor" production in some referent.

Price determination

Price is a function of producers' base price, production costs, and a markup factor. Producer price is determined by the capacity utilization rate. Its influence on final price and on the decline rate depends on its initial size as well as on market conditions. The markup factor takes into account capacity utilization in the production process, the impact of the decline rate, and the gap between the consumer countries' demand for imports from the Gulf and the Gulf's ability to meet that demand. Markup is a dynamic, endogenously determined influence on price. Through markup, the system-wide supply and demand conditions influence price, and in turn prices influence the prevailing conditions in the oil market as a whole. The ratio of markup to total price differs under different market conditions and size of the producers' base price.

Adjustment mechanisms

The IPE model combines the characteristics of two types of economic models -- the dominant firm model for a short-run analysis and a longer-run adjustment process of quantities to price. The dominant firm model applies to the Gulf producers who make price and quantity decisions in the short run by setting the base price of crude and/or the amounts to be produced or capacity to be utilized and in the longer run on the size of the residual market (where excess demand is met in the short run by non-Gulf producers) and on the price responsiveness of demand.

In the short run consumers can influence the size of the residual supply, increase domestic production, and to some extent cut their imports. In the longer run they can adjust demand and expand the use of alternative sources of energy.

As the markup factor represents the immediate adjustment to prevailing market conditions, it is intended to reflect the oil industry's (the international corporations') influence on and responses to market conditions. In the longer run the oil industry influences exploration and development through their investments in oil.[10]

Computational structure

The IPE model is composed of seven sectors, designed to represent the physical characteristics of oil production, the economic context and constraints, and the international financial exchanges that ensue from the trade in oil. See Figure 2 for sectoral relationships.

- the supply sector represents the physical stages of oil production, tracing the process from exploration for oil-in-place and the development of recoverable reserves to the installation of productive capacity and actual production.

- The finance sector calculates oil import expenditures for consumer countries, corporate profits and oil investments for the oil companies, and oil revenue for the producer countries.

- The management sector specifies investment decisions affecting the supply of oil. For analytical purposes, the model specifies the major investments of the multinational corporations in development and exploration, based on information drawn primarily from the supply sector, in conjunction with considerations of oil demand from the consumer sector. (Investments are separated from the agent, i.e., countries vs. corporations.)

---

[10] Due to changing jurisdictional conditions, this markup factor can be incorporated in producer country behavior. Originally, however, it was designed as a means of explicitly incorporating the international oil companies as distinct actors in the world oil market.

- The price sector calculates oil price based on inputs from other sectors. Producer price is endogenous; production costs and the corporate markup are also taken into account. Once calculated, the effects of price are then transmitted throughout the model to compute its financial and security implications for producers and consumers.

- The producer sector models the process of industrial development that generates demand for development investments and for imports of goods and services.

- The consumer sector computes demand for oil imports and monitors consequences for the consumers' strategic vulnerability and dependence upon external sources of supply. Domestic supply and demand and energy substitutes are specified.

- The international economic sector calculates the consumer balance of payments and traces the foreign investments of the producing states; it registers and links the consequences of actions taken by the consumer countries, the producers, and the international oil companies. (This sector helps achieve "closure.")

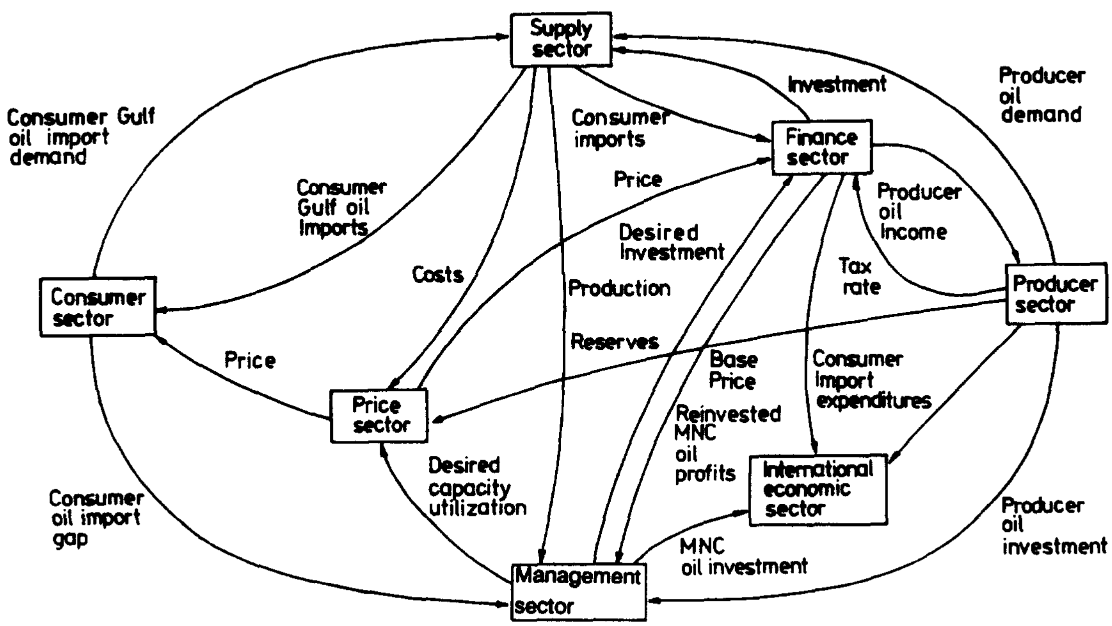

Figure 2. Select linkages -- sector link diagram.

Note: Only one component of markup is derived in the management sector.

Source: Nazli Choucri with David Scott Ross: International Energy Futures: Petroleum, Prices, Power, and Payments. Cambridge, Massachusetts: The MIT Press, 1981, p. 38.

The time frame of the IPE model is 1970-2000. Few experiments have been run beyond 2000, although they are technically feasible. Results are presented at annual intervals; however, the actual computations are done over 10 increments per year. The demand, supply, and price formulations are computed iteratively. The flow chart diagram for the consumer sector is given in Figure 3 to show the DYNAMO conventions for representing feedback and functional relationships.

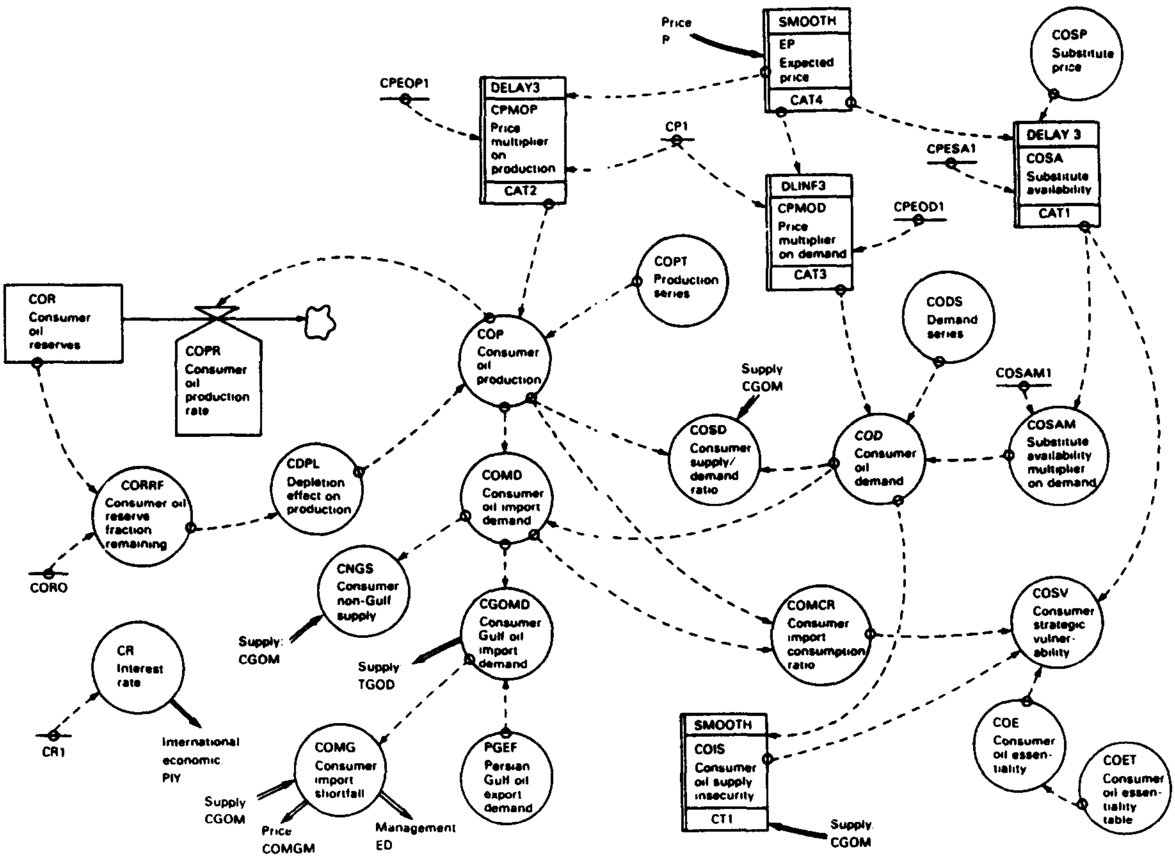

Figure 3. Computer flow diagram of the consumer sector.

The IPE model has been disaggregated on both the supply and demand sides to enable analysis and simulation of the behavior of individual agents and actors in the world oil market. The initial disaggregations were for the EMF 6 exercise as indicated above, and further refinements are currently being made for the EMF 11 exercise. Space limitations preclude a detailed discussion of the disaggregation strategy, results, and implications for policy analysis.

Source: Choucri (1981: 106).

Re-specification of the IPE model

The following regional sectors and the individual disaggregated components have been in the IPE model:

- OECD, aggregated from individual sectors representing the United States, Western Europe, Japan, and Canada-Australia-New Zealand (CAO);

- OPEC, aggregated from Middle Eastern (including Algeria and Libya) and non-Middle Eastern sectors;

- other Third World countries.

This disaggregation is designed to test for adjustments of, and effects on, individual (national and regional) behavior and to improve policy analysis by embedding the characteristic features of different buyers and sellers in the model (via functional relationships and parameter values).

Re-specification of supply and demand

Demand estimation. Three types of demand functions are used in the IPE:

- OPEC demand is estimated by means of regression estimates determining the response of demand to change in oil income, population levels, and non-oil GDP.

- Mexico demand is estimated using initial (1970) demand, assuming a certain price-independent growth rate and modifying this by means of a long-term price elasticity.

- OECD and other Third World demand is based on a more complicated growth mechanism with feedback from oil prices, modified by long- and short-term demand elasticities.

Supply estimation. Oil production is determined as follows:

- For Canada-Australia-New Zealand, production is equal to the minimum of 95 percent of capacity or total demand. Production capacity is derived from initial capacity and a price multiplier.

- Non-OPEC Third World production is set at maximum levels, 90 percent of capacity. The difference between production and demand is exported.

- Mexican production is determined directly from a base series, modified by a price elasticity.

- U.S. production is determined by price and depletion, modifying the initial production series; Western Europe production uses price and depletion, modifying a production series which increases to show the effect of the North Sea coming on-line in the 1970s; Japan production is set at zero.

- Capacity utilization for the two OPEC groups (Middle East and non-Middle East) is determined in part concurrently; actual capacity is determined separately and with a different specification. Middle Eastern capacity is determined by investments based on estimated demand. Non-Middle Eastern capacity is based on an initial level, modified by a price multiplier and reserve depletion. Capacity utilization is calculated by: (a) setting aside sufficient capacity to meet domestic demand, then (b) sharing the remaining capacity equally between Middle East and non-Middle East producers.

- Synfuels, defined as liquid fuels derived from coal or oil shale, are produced only in the U.S. sector, using a price-adjusted (0.3) base production series. The base series assumes 50,000 barrels per day will be produced by 1990 and 5 million barrels per day by 2000.

Economic growth

Base economic growth for the major consuming regions is supplied exogenously (see above demand analysis). For most regions, growth is estimated to range in the 2 to 3.5 percent interval.

Economic growth in OPEC countries is estimated in the form of non-oil domestic capital, which is a function of investment and depreciation. Investment is derived from regression estimates on population, oil income, and existing non-oil capital. Capital is assumed to be 2.5 times total GDP, a rough indicator commonly used in development economics.

Price specification

Price is generated endogenously; alternatively it can be used as a policy variable (by modifying the base price exogenously). Computationally, the base world price is with production costs and markup added to yield final price. The endogenous mechanism represents the tightness of the market (as measured by the capacity utilization in the Middle East) and the decline rate. For simulation purposes the capacity utilization rate is specified as a basis against which adjustments occur.

The higher the capacity utilization (over the specified percent and subject to change for policy analysis), the greater will be the price increase (the lower the rate, the less the impact on price). The model is designed so that different degrees of responsiveness can be examined. (The decline rate of reserves has a relatively small impact overall in the market.)

5. RESULTS OF IPE SIMULATION

Of the many ways to illustrate the behavior and validity of simulation models, we have undertaken three strategies: (1) comparing model results for the reference (base case) to actual known values (here, 1970 to 1986); (2) comparing IPE model results with those generated by other world oil models; and (3) examining behavior for internal consistency and plausibility, given known parameters of the world oil market.[11] Here we present the results of the first type of validity -- a comparison of major IPE outputs with the historical record.

Table 2 shows the actual vs. IPE values for Central Planned Economies (CPE) world oil supply, demand, and prices, 1970 to 1986.

Table 2. IPE Base Case Results and Historical Record.

	Non-CPE World Supply		Non-CPE World Demand		Price -- 1980$'s	
Date	Actual	IPE	Actual	IPE	Actual	IPE
1970	38.1	39.1	39.0	39.6	4.30	4.13
1971	40.0	41.3	41.1	41.9	4.81	4.20
1972	42.1	43.6	43.9	44.2	5.42	4.45
1973	45.9	45.6	47.4	46.4	5.47	4.67
1974	47.6	46.8	45.8	47.7	17.83	11.34
1975	43.9	44.3	44.6	45.2	16.68	16.78
1976	47.4	45.1	47.4	46.1	16.84	16.90
1977	49.1	46.3	48.9	47.7	17.11	17.06
1978	48.9	48.4	50.3	49.5	16.23	17.24
1979	51.3	49.9	50.9	51.0	18.23	17.42
1980	47.9	48.3	48.3	49.5	28.00	29.17
1981	44.5	45.4	46.5	46.9	29.80	28.90
1982	42.1	43.7	45.1	45.5	30.47	28.67
1983	41.5	42.9	44.9	44.9	26.82	28.65
1984	42.9	42.7	45.5	45.0	25.07	28.18
1985	42.5	42.9	45.3	45.4	24.07	27.39
1986	44.6	44.5	46.4	46.9	13.00	16.76

Sources: British Petroleum, BP Statistical Review of World Energy, various years, and 20th Century Petroleum Statistics, 1986).

[11] See Choucri (1981) for detailed results of the initial IPE validation analysis. The model is updated approximately every three years. The first version was written in two years. A typical updating effort takes about 3 man-months.

6. SIMULATION OF ENERGY DEMAND

To demonstrate the demand side of the IPE model, two price simulations are shown below: the base case vs. the high price scenario.

The base case price is endogenously determined by the IPE model. The IPE makes two assumptions regarding the future availability of crude oil reserves and the pace of energy conservation which tend to distinguish it from other forecasts: (a) it holds a somewhat "optimistic" outlook for future crude oil discoveries and (b) it assumes that conservation and fuel switching will persist, as will further development of oil-saving technologies. IPE therefore generates both lower demand and greater non-OPEC supply than most other models of the world market. The IPE currently forecasts (endogenously) real oil prices to remain flat in the $18-$20 per barrel range (in real terms) for the foreseeable future (i.e., the year 2000).

The high price case is based primarily on existing conservative estimates of reserves of non-OPEC producing countries and lower economic growth among industrial nations, roughly in the area of 2.5 percent.[12] Implicit in the high price case is the assumption that the energy to GNP ratio will end its current slide and that oil demand in the future will be highly inelastic. A corollary is the presumed ability of OPEC to regain almost complete control over all pricing, including a capacity to significantly raise real prices over the long run, in spite of substantial gains in energy conservation. A price comparison is given in Table 3.

Table 3. World Oil Price: Two Contending Forecasts.

	(1986 Dollars)	
	IPE Base	High Price
1986	20.10	14.02
1987	18.79	18.50
1988	18.30	18.51
1989	18.35	20.53
1990	18.36	22.55
1991	18.39	23.58
1992	18.44	24.59
1993	18.51	25.55
1994	18.61	26.53
1995	18.72	27.45
1996	18.99	28.56
1997	19.12	29.58
1998	19.21	30.57
1999	19.28	31.58
2000	19.38	32.58

Figure 4 compares the results for energy demand of the alternative price scenarios. The demand for petroleum is lower in the high price case over the long run. Though all regions show some demand increases under this higher price scenario, for some regions, this growth is minimal. Not shown here, for example, Western European demand is projected to increase only .3 percent (total, not per annum) between 1986 and 2000 in high price case. U.S. oil demand, after moderate increases through the late 1980's, shows virtually no growth throughout the 1990's under

[12] U.S. Department of Energy (1987). (Since this DOE scenario only extended to 1995, prices in the IPE beyone 1995 were extrapolated.)

this scenario. Most other regions (not shown here) display increases of only 8-10 percent (total) over the interval from 1986 to 2000.

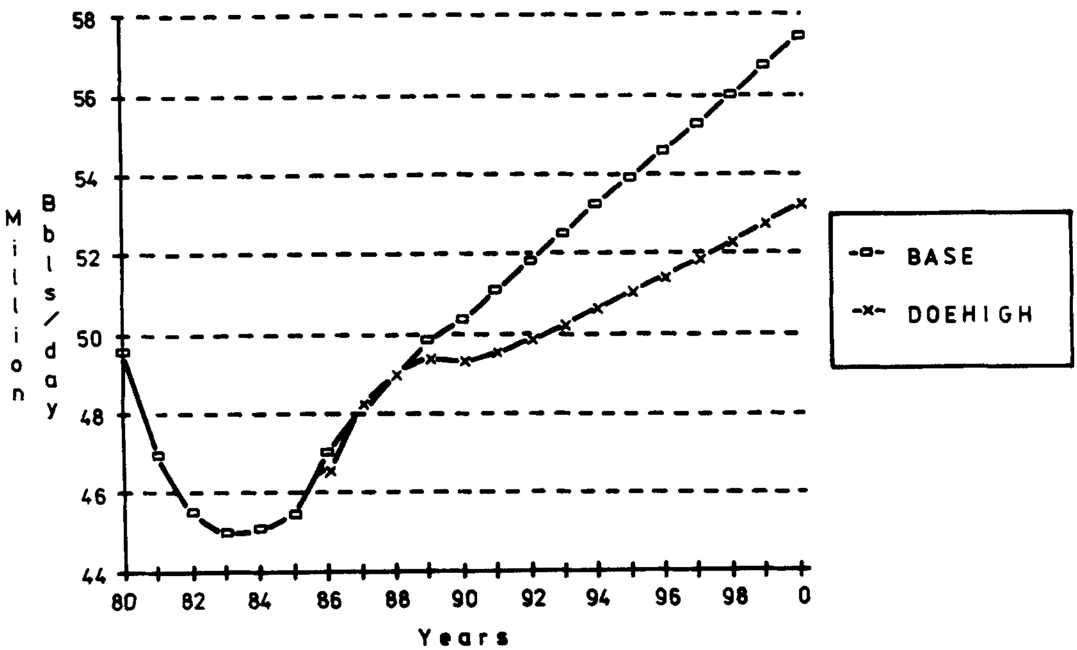

Figure 4. Scenario Comparisons: World non-CPE Oil Demand

7. CONCLUSION

This discussion of simulation approaches to policy modeling focuses on system dynamics, with a partial comparison with econometric simulation. The structure, respecification, and system behavior of the International Petroleum Exchange model were presented to illustrate the design of a simulation model of the world oil market. Finally, a simulation of the demand side was undertaken showing model behavior in two cases: the base case vs. the high price case.

The IPE model simulates all major CPE suppliers, thereby tracking the interdependence between OPEC and non-OPEC suppliers. Although the primary focus of this discussion has been the model's restructured demand specifications, the supply and price sectors of the IPE model are modeled in considerable detail. The supply sector, particularly that of the OPEC producers, has greater empirical grounding than the demand specifications. The IPE model is distinctive, even unique, among energy models in the degree of attention it pays to behavioral characteristics of the OPEC suppliers. The financial aspects of production, including both producer government and multi-national oil company activities, are particularly well specified.

Because we regard OPEC behavior as crucial to the determination of world oil prices, we have recently embarked on a new effort to model the internal activities of OPEC in even greater detail.[13] Specifically, we are attempting to model the decision rules for production sharing within OPEC itself. Price changes can best be understood by examining the production arrangements conferred and abrogated by OPEC. Market structure since 1985 reflects the importance of non-OPEC countries and the extent to which OPEC behavior affects global production and supply.

[13] Currently being completed is a detailed re-specification of the supply-side to differentiate among the behavioral "rules" used by different OPEC countries in their determination of production. These "rules" are embedded in differences among them with respect to reserve, production capacity, and capacity utilization. This module can be run autonomously (and is labelled CAPRO model).

REFERENCES

Adelman, M. A. (1972). The World Petroleum Market, Baltimore: Johns Hopkins Press.

British Petroleum Review of World Energy, various issues.

Coucri, Nazli with David Scott Ross (1981). International Energy Futures: Petroleum Prices, Power, and Payments, Cambridge, Mass.: MIT Press.

Choucri, Nazli and Thomas W. Robinson, eds. (1978). Forecasting in International Relations: Theory, Methods, Problems, Prospects, San Francisco: W. H. Freeman.

Choucri, Nazli, Christopher Heye, and Michael Lynch (1989). "Analyzing Oil Production in Developing Countries: A Case Study of Egypt," MIT: Department of Political Science.

Energy Modeling Forum (1982). "World Oil," EMF Report #6, Vol. 2.

Forrester, Jay W. (1961). Industrial Dynamics, Cambridge, Mass.: MIT Press.

Forrester, Jay W. (1968). Principles of Systems, Cambridge, Mass.: MIT Press.

Forrester, Jay W. (1971). World Dynamics, Cambridge, Mass.: Wright-Allen Press.

Goodman, Michael R. (1974). Study Notes in System Dynamics, Cambridge, Mass.: Wright-Allen Press.

Meadows, Dennis et al. (1972). The Limits to Growth, New York: Universe Books.

Petroleum Economist, various issues.

Pindyck, Robert S. (1979). The Structure of World Energy Demand, Cambridge, Mass.: MIT Press.

Richmond, Barry, Steve Peterson, and Peter Vescuso (1987). An Academic User's Guide to STELLA, Lyme, N.H.: High Performance Systems Inc.

Shearer, J. Lowen, Arthur T. Murphy, and Herbert H. Richardson (1971). Introduction to System Dynamics, Reading, Mass.: Addison-Wesley Publishing Company.

U.S. Department of Energy (1987). International Energy Outlook 1987, Washington, D.C.: U.S. Government Printing Office.