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ABSTRACT

The United States is currently undergoing a transition from rapidly depleting nonrenewable energy sources to "backstop" energy sources. Unlike previous transitions, the current transition will be marked by rising real energy prices and may profoundly affect the economy. Despite the acknowledged urgency of the problem, there is little agreement on the nature of the connections between energy and the macroeconomy.

A system dynamics model is developed to analyze the macroeconomic effects of the energy transition. GNP, consumption, investment, wages and prices, and other major energy and economic aggregates are determined endogenously. Though the model generates macroeconomic dynamics, it is based on an explicitly causal, behavioral theory of decisionmaking at the microeconomic level of individuals and firms.

The model shows how delays in substitution and the development of new energy sources arise and lead to substantial economic vulnerability during the next several decades.

The model is used to analyze the effects of government subsidies for energy technologies. The effects of subsidies for long-lead time, capital intensive centralized technologies are contrasted against subsidies of short lead-time, labor intensive, decentralized technologies; the latter are found to be far more effective in reducing the vulnerability of the economy during the transition.

ECONOMIC VULNERABILITY AND THE ENERGY TRANSITION [1]

1. Energy and the Economy

The 1970s may well be remembered as a turning point in the economic history of the United States. In 1970, domestic production of petroleum peaked. Two years later, production of natural gas peaked [2]. Less than two years later, the economic and strategic vulnerability of the United States was forcefully demonstrated by OPEC, leading to the call for energy independence. The rest of the decade brought a succession of disappointments and lowered expectations. Both oil and gas output declined steadily. Coal was again hailed as king but failed to ascend the throne. Nuclear power generated a critical mass of safety, environmental, and ethical opposition which has brought its development to a virtual standstill. As the nation enters the last decades of the twentieth century, oil imports remain at dangerously high levels, and alternative energy sources remain largely untapped. The nation has been thrust into a major energy transition. Unlike the previous transitions from wood to coal and from coal to oil, the current transition will be marked by rising real energy prices. Never again will the nation enjoy energy as abundant, inexpensive, and environmentally benign. [3]

Since 1973 there has been growing awareness that the energy transition will be more difficult, time consuming, and expensive than anticipated. There are already many signs of economic stress. During the 1970s, economic growth faltered from the 3.7%/year rate of the 1950s and 1960s to 2.7%/year. The nation experienced the two deepest recessions since the Great Depression, high unemployment, large trade deficits, slackened productivity growth, and the most severe peacetime inflation in U.S. history. While not all the nation's economic woes can be traced to energy, the impact of energy on the economic health of the nation is undeniable. The unemployment, factory shutdowns, hardship, and inconvenience caused by the OPEC embargo of 1973, natural gas shortages of 1976, coal strike of 1978, and gasoline shortages of 1979 all demonstrated the vulnerability of a modern industrial economy to disruptions in energy price and availability. But energy also creates vulnerability in more subtle ways: energy prices outpaced inflation for most of the decade, raising the real price of energy and adding

to inflationary pressures; growing capital requirements for energy production threaten investment in other sectors of the economy; the costs of producing synthetic fuels and other alternative sources rise as OPEC prices rise; and high OPEC prices transfer income and wealth from oil consuming nations to oil producing nations.

Despite the signs of stress and the acknowledged urgency of the problem there is little agreement on the nature and relative importance of the myriad interconnections between energy and the economy. A framework is needed to integrate in a consistent and realistic manner the dynamic effects of energy depletion and rising energy costs on economic growth, inflation, and the standard of living.

This paper describes such a framework and its application to energy policy analysis. The framework consists of a system dynamics model of the national economy. Based on an explicitly causal theory of economic behavior at the level of individuals and firms, the model endogenously generates the major energy and economic aggregates including GNP, consumption, investment, real and nominal wages and prices, the rate of inflation, interest rates, and energy production, imports and prices. Because of the model's detailed behavioral representation of the physical and decision-making structure of the various sectors of the economy, policy initiatives such as price controls, tax credits, and subsidies for energy production can be tested realistically in a macroeconomic context.

Understanding of the dynamics of energy-economy interactions is just developing. The analysis presented below focuses on the underlying structural causes of the macroeconomic effects of energy policies over the long term. The purpose is not to forecast energy use or the rate of economic growth, nor is it to predict that there will or won't be an energy-induced depression in the next decade. Such predictions are not useful and may be impossible in principle. [4] The record of the past decade amply demonstrates the practical impossibility of predicting energy use, production, or prices. It has been well said that "if you jump out of an airplane, you are better off with a parachute than an altimeter." [5] It is the purpose of this study to aid in the design of the parachute.

2. Some Difficulties in Energy-Economy Analysis

The energy crisis was initially perceived as a supply problem: domestic production was dropping; imports were rising. Thus the first generation of energy models were designed to explore ways to increase production to meet projected demands while keeping energy prices relatively low, and assuming historical rates of economic growth. [6] Though the extent to which market interactions between supply and demand are included in such models varies, nearly all the early energy models treated the energy sector in isolation from the rest of the economy, including the assumptions that GNP, interest rates, inflation, capital availability, backstop energy costs, and OPEC prices are all unaffected by the availability and price of domestic energy. The supply models generally showed that to satisfy projected energy demands and reduce imports, the energy sector would require massive amounts of capital, financed by large increases in the real price of energy. [7] Yet the resulting high energy prices and drain of investment from other sectors of the economy are inconsistent with the original input assumptions of moderate increases in energy costs and vigorous economic growth. As a result, the supply models were far too optimistic, causing their builders to lower estimates of future economic growth and raise estimates of future energy prices. Failure to incorporate the feedbacks between the energy sector and the macroeconomy compromised the results of the the supply models.

A second generation of energy models was developed to deal with the interactions between energy and the economy. [8] The energy-economy models suggest the economy can accommodate itself to higher energy prices without severe reductions in the standard of living. However, these models often ignored the adjustment path of the economy to higher energy prices, assuming instantaneous adjustment to the long run equilibrium, such as the assumption that the energy required to utilize existing capital responds instantaneously to an increase in prices. [9] Other models assume perfect information about future energy demand, supply, and prices is available to decision makers. [10] Because these models lack a behavioral theory of economic decisionmaking and fail to account for the physical lags in the economy they provide no comfort in assessing the prospects for the transition period, and little aid in evaluating the likely response of the economy to policies. Mork and Hall summarize the problem:

...a successful analysis of an energy price shock [and more generally, depletion] must integrate two equally important aspects. On the one hand, the long-term effects of energy substitution must be incorporated. This is done in most general equilibrium energy-economy models, but these are long-term growth models and [are] not intended for analysis of short-term problems. All the existing large short-run macroeconomic models lack this feature to our knowledge.

On the other hand, the short-run effects on price level, financial markets, and employment must be taken into account. As equilibrium models of the real economy, the energy-economy growth models naturally abstract from these phenomena. Short-term macroeconomic models include them, or can be modified to include them. However, a fully satisfactory treatment of the problem requires an integration of the long- and short-run mechanisms. [11]

To address questions of economic vulnerability during the energy transition and to assess energy policies, the model described below represents the physical and technical relationships in the economy and the decisionmaking processes used by the actors in the system at the detailed, micro-level of individuals and firms. Both the physical structure of the economy (the stock and flow networks of people, goods, energy, and money) and the decision-making structure of the various actors in the system (the decision rules and the information sources for decisions) are represented.

By modeling the decision-making of the actors in the system and the delays, constraints, and inadequate information that often confound them, the macro-level dynamics of the economy emerge naturally out of the interaction of the components of the system. Because such models provide a rich behavioral description of the economy firmly rooted in managerial practice, they are particularly well suited for examining the dynamic effects of policy initiatives. [12]

In addition to a detailed behavioral representation of economic decisionmaking, the model incorporates a wider boundary than found in many other energy models (Table 1). A wide boundary is necessary to ensure the feedback mechanisms that may delay or dilute the intent of a policy are adequately represented.

The endogenous variables include the major economic and energy aggregates. The model also endogenously generates a wide variety of variables on the sectoral level such as output, employment, wages, investment, prices, return on investment, liquidity, debt, and dividends. The exogenous variables represent variables unlikely to be influenced strongly by the evolution of the

Table 1: Summary of Model Boundary

<u>ENDOGENOUS</u>	<u>EXOGENOUS</u>	<u>EXCLUDED</u>
GNP	Population	Inventories
Consumption	Technological	International
Investment	Change	Trade (except
Savings	Tax Rates	with OPEC)
Prices (Real	Energy Policies	Environmental
and Nominal)		Constraints
Wages (Real		Non-energy
and Nominal)		Resources
Inflation Rate		Interfuel
Labor Force		Substitution
Participation		Distributional
Employment		Equity
Unemployment		
Interest Rates		
Money Supply		
Debt		
Energy Production		
Energy Demand		
Energy Imports		

energy-economy system (such as population); variables representing specific policy levers the model user wishes to test (such as energy policies and tax rates); and variables such as technological progress and OPEC actions whose coupling to the economy may be important but for which development of an endogenous theory is too large a task given the model purpose.

The concepts and issues excluded from consideration are of particular interest since they define the boundary of the model, delimit the issues for which it can be legitimately used, and suggest likely avenues for further research.

Inventories: Energy depletion and the subsequent adjustment of the economy is a process requiring decades. In comparison, adjustments to inventories of goods and energy are short-term phenomena and can thus be ignored without compromising the conclusions of the study. As a result, the model does not deal with the short-term business cycle. [13]

International trade is excluded except for energy imports from OPEC and the recycling of import revenues. Though non-energy trade is influenced by energy prices and availability, the purpose of the model does not require an evaluation of the effects of energy imports on the exchange rate or competitiveness of U.S. manufactured goods in the world market.

Environmental constraints (such as clean air standards) and possible scarcity of non-energy resources (such as water for synfuel development) are quite important. The direct economic costs of environmental constraints can be partially captured in the model by including the costs of meeting environmental standards in estimates of the capital, energy, and labor requirements of the various sectors of the model. But interactions between the production of energy and the environment (such as aquifer depletion or acid rain) and the potential long-term effects of pollution (such as carbon dioxide buildup) cannot be assessed.

Interfuel substitution: To gauge the broad impact of depletion on the economy it is not necessary to represent different fuel types or to distinguish between oil, gas, oil shale, underground and surface coal, nuclear power, etc. Such disaggregation would be required to address, for example, possible liquid fuel constraints, the environmental impacts of direct coal combustion versus liquefaction and gasification, or the consequences of further electrification, issues that, while important, lie outside the scope of the present study.

Distributional equity: The energy transition could have important effects on the distribution of income among different social groups. Certain sectors of the economy will suffer; some energy-intensive industries may vanish while new industries will surely appear. There may be important geographical shifts in economic activity. These issues are all outside the scope of the study and cannot be addressed with the current model.

3. Model Structure

The model represents the national economy and energy system, including OPEC. There are five major sectors (Figure 1): production, household, financial, government, and OPEC. The production sector actually consists of four distinct production sectors: the goods sector, producing consumer goods and services; the capital sector, producing capital plant and equipment and housing; and the nonrenewable and backstop energy sectors, corresponding respectively to nonrenewable energy sources and alternative sources.

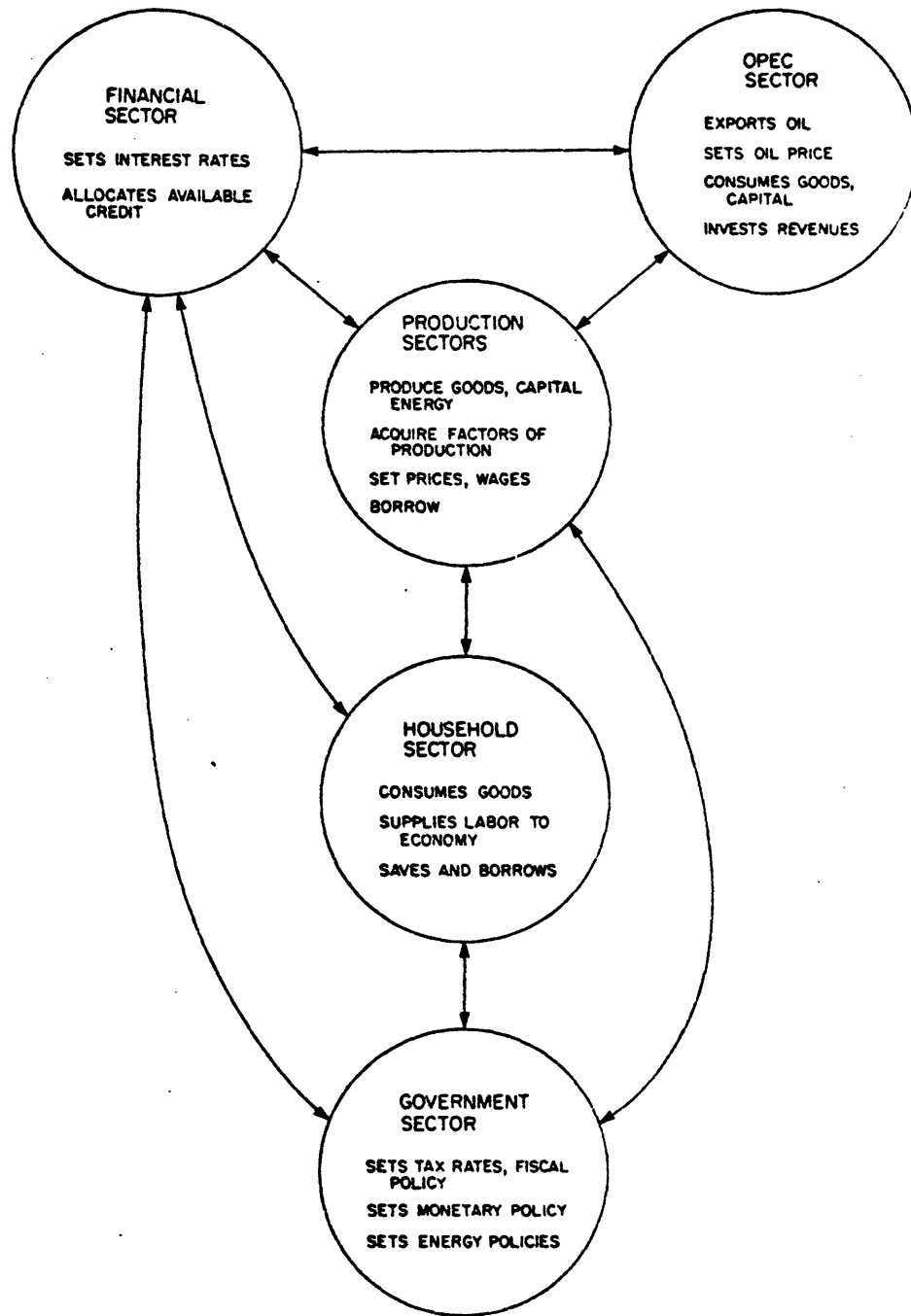


Figure 1: Overview of Model Structure

The household sector supplies labor to the production sectors and receives wages and profits as income. The household spends most of its income on goods, housing, and energy and saves the rest for investment in the production sectors. The financial sector sets interest rates and allocates available savings among competing demands for credit. The government sector interacts with the financial sector through monetary policy and is also responsible for collecting and disbursing taxes and conducting fiscal and energy policy. Finally, the OPEC sector supplies energy to the domestic economy, recycling its revenues by purchasing goods from the production sectors and investing in the assets of the domestic economy.

The production and household sectors form the heart of the model; Table 2 summarizes their definitions and relates them to the major industry groupings of the National Income Accounts; Figure 2 shows the physical flows of goods, capital, and energy between the production, household, and OPEC sectors.

The goods sector supplies goods and services to both households and OPEC. The capital sector supplies plant and equipment to all the sectors including the OPEC sector, the household sector (where capital represents housing), and to itself. Similarly, the energy sector (nonrenewable and backstop energy taken together) delivers energy to all the sectors except OPEC. Corresponding to the network of physical flows shown in Figure 2 are analogous but distinct networks of orders and payments.

The treatment of energy merits special attention. Energy is represented in terms of BTUs of heat value. [14] Energy production has been divided into the three broad categories of nonrenewable energy, backstop energy, and imports. The nonrenewable energy sector is dependent on a resource base which is gradually depleted. As depletion occurs, the marginal cost of discoveries rises. In contrast, the backstop energy sector represents both renewable energy sources (such as solar, biomass, and small-scale hydropower) and nonrenewable sources which draw on very large resource bases (such as shale oil, coal synthetics, and nuclear power). [15] Depletion of these sources is not likely to be significant within the time horizon of the study. The backstop sector can be calibrated to represent different alternative technologies by varying its cost structure and the input mix of capital, labor, and energy. But whereas the quantity of capital, labor, and

Table 2: Sectoral Definitions

<u>Sector</u>	<u>Definition</u>	<u>Major Industry Groups</u>
Goods	Produces consumer goods and services, including government services	Agriculture, consumer durables consumer nondurables, services, transportation, government services, including military
Capital	Produces capital plant and equipment and housing, includes non-energy raw materials	Contract construction, metal mining, non-fuel nonmetallic mining, machinery, stone, clay, and glass products
Nonrenewable energy	Produces nonrenewable energy	Petroleum, natural gas, conventional coal (coal not used for synfuels)
Backstop Energy	Produces alternative energy sources. Corresponds to "backstop" energy sources	Shale oil, coal synthetics, nuclear power, solar energy, all energy sources not considered conventional sources.

		CONSUMING SECTOR				
		GOODS	CAPITAL	ENERGY	OPEC	HOUSEHOLD
SUPPLYING SECTOR	GOODS				✓	✓
	CAPITAL	✓	✓	✓	✓	✓
	ENERGY	✓	✓	✓		✓
	OPEC			✓		
	HOUSEHOLD (LABOR)	✓	✓	✓		✓

A ✓ INDICATES DEPENDENCE OF THE CONSUMING SECTOR ON THE OUTPUT OF THE SUPPLYING SECTOR

Figure 2: Physical Flows Between Sectors

energy required to produce nonrenewable energy rises as more of the resource is extracted, the amount of capital, labor, and energy required to produce backstop sources remains the same. (However, as in each production sector, the actual factor mix can change in response to varying relative prices and the availability of the factors of production.)

The concept of the backstop is a useful but considerable simplification of reality. Many of the energy sources commonly cited as "backstops" are in fact nonrenewable sources such as oil shale, coal synthetics, and nuclear. And few if any of the alternative sources are so abundant and evenly distributed that they can boast a flat supply curve: even solar energy will grow more expensive on the margin as south-facing slopes and the regions with the highest insolation are developed.

The assumptions made in the model about backstop energy are likely to underestimate the costs of producing backstop energy and overestimate its availability. To paraphrase Solow, the technologies trying out for backstop may be catchers who allow some passed balls. [16] Since the purpose of the model is to demonstrate the importance of the macroeconomic effects of the energy transition in designing energy policy, the model's optimistic representation of alternative energy sources is appropriate: if the model demonstrates the potential for significant macroeconomic effects even when backstop energy is assumed to have such optimistic properties, a more disaggregate and realistic treatment of the backstop technologies that included depletion, supply curve effects, and environmental constraints would produce effects at least as large.

The determination of energy demand is a crucial part of the model structure and is presented below as an example of the level of detail represented in the model. The energy each sector requires to operate is tied to the sector's capital stock. A firm may have a wide menu of efficiencies to choose from when deciding on the specifications of new investment, but once that investment is made, the energy required to operate the capital is largely fixed. Many models account for the rigidity in energy requirements by employing a putty-clay approach in which there is complete flexibility of factor proportions ex ante investment and complete rigidity ex post. However, the assumption that energy requirements are fixed ex post investment makes no allowance for "additional home and plant insulation, automobile tuneups, and

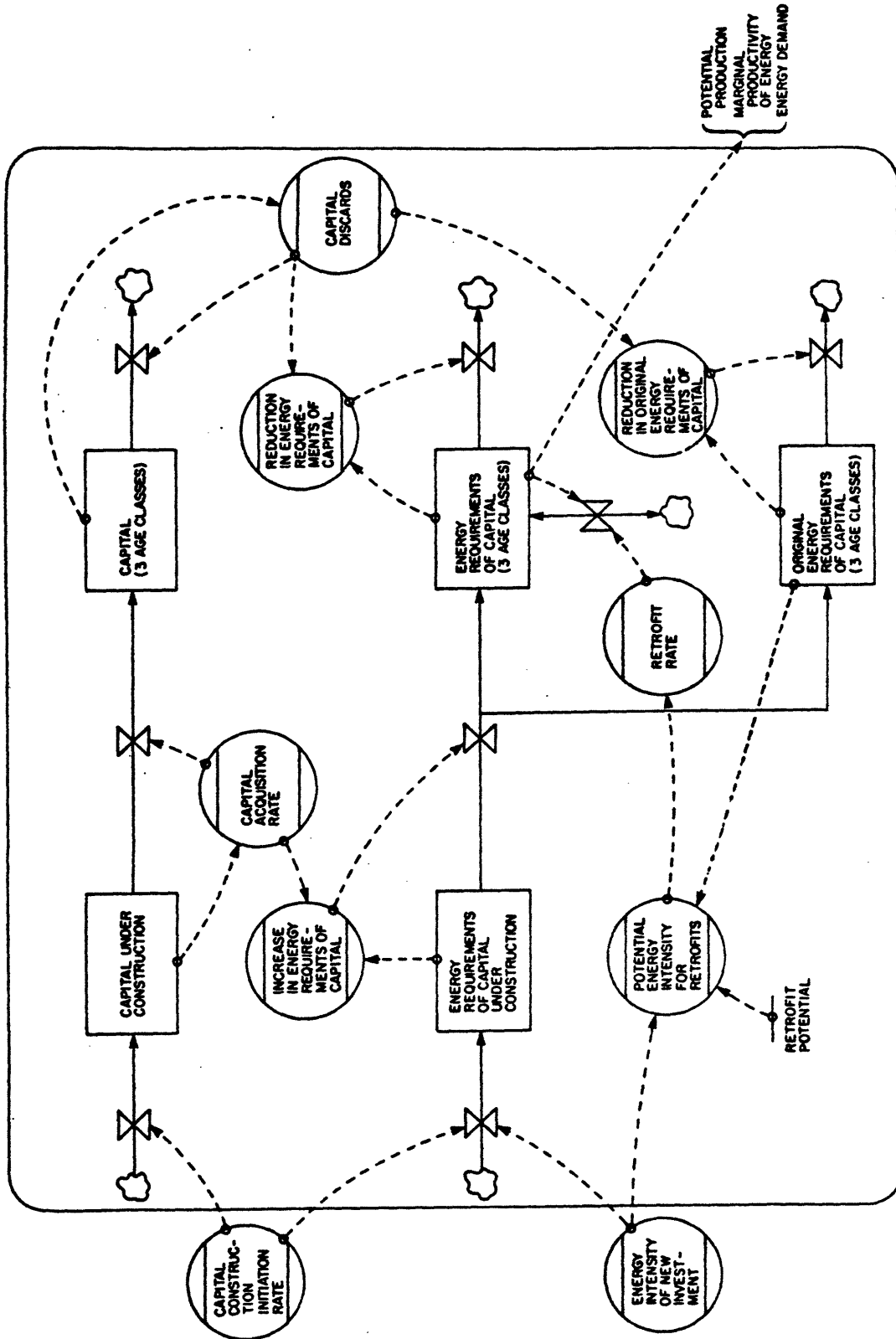


Figure 3: Simplified Representation of Determinants of Energy Use

retrofitting of certain industrial processes to utilize waste heat." [17] Many studies favor retrofits and conservation as the cheapest 'source' of energy. [18] To examine the crucial issue of retrofits, the model employs a variant of the putty-clay approach which both binds the energy requirements of each sector to its capital stock and explicitly includes retrofits (Figure 3).

The model keeps track of the energy required to operate each unit of capital beginning with the construction of new units. When construction is completed, the sector's capital stock is increased; the energy requirements of the capital stock are increased in proportion to the energy intensity of the new units. As the capital ages (three vintages of capital are represented) and is ultimately discarded, the energy requirements of the sector are diminished by the energy intensity of the discarded units. The decision to undertake retrofits is based on principles of economic optimization: firms compare the (perceived) marginal revenue product of additional energy use to the marginal cost of energy and adjust the desired energy intensity accordingly. [19] If energy prices rise, firms will undertake to reduce the energy intensity of new investment and the energy intensity of existing capital (in accordance with the long-run substitution possibilities). However, the ability to bring existing capital up to the efficiency of new units is constrained by the physical characteristics of the existing units (represented in the model by the original energy requirements of capital). For example, the optimal amount of insulation in a house might be eight inches, but if the walls are four inches thick, a retrofit, though still potentially worthwhile, can not bring the house up to the optimal efficiency. The model allows the degree to which the original characteristics of capital constrain retrofits to be varied by specifying the retrofit potential. If existing capital so constrains the possibilities that no retrofits are economically feasible, the retrofit potential is zero, as in a putty-clay model; if no constraint exists, the retrofit potential is 100%, a putty-putty situation. Thus the model allows any degree of ex post flexibility to be represented.

Parameters and initial conditions were estimated with numerical data where available such as the time series available in the National Income Accounts, Historical Statistics, and other government sources. In addition, econometric estimation reported in other studies and qualitative information reported in the economics, management, and engineering literature have been

used where numerical data are insufficient. [20] Yet because the model structure is behavioral and causal rather than statistical and correlative, numerical data were unavailable to estimate many parameters. Faced with a number of relationships and parameters with uncertain values, sensitivity analysis is crucial. It is useful to define three types of sensitivity: numerical, behavioral, and policy sensitivity. [21] A model is numerically sensitive when a change in parameters causes a change in the numerical values of the output. All mathematical models are numerically sensitive. A model is behaviorally sensitive when a change in parameters causes a change in the dynamic pattern of behavior, for example, a change from oscillation to stability or from growth to collapse. Finally, a model is policy sensitive when a change in assumptions changes the characteristic response of the system to policy interventions. For example, an energy excise tax would be policy sensitive if the system exhibited a strong trade-off between the short- and long-run effects of the policy under one set of assumptions but not under some other set of conditions.

The type of sensitivity that is relevant and hence the role of data in any application depends on the purpose of the model. To pose questions about possible amplification of the effects of depletion and the potential for delays to worsen the intermediate-term impact of depletion is to ask about behavioral tendencies of the system. To address the macroeconomic consequences of policy interventions is to ask about policy effectiveness. Thus behavioral and policy sensitivity are the relevant measures of model sensitivity.

System dynamics models and, more generally, feedback control models typically exhibit insensitivity of behavior modes and policy responses to changes in the vast majority of parameters and relationships. [22] If the characteristic modes of behavior and response to policies are insensitive to variations that span the range of uncertainty in a given relationship, then there is no need for great precision in the estimation of that relationship. Time and resources are best spent elsewhere. Indeed, one of the purposes of model building is to identify those few relationships that are sensitive to guide further research and policy design. Sensitivity analysis of the model showed the modes of behavior and policy responses described below to be invariant with respect to changes in major assumptions. [23]

4. Base Case Assumptions and Historical Comparison

The major assumptions of the base case appear in Table 3. The assumptions represent a fortiori estimates: where uncertainty exists, the choice errs on the optimistic side. [24]

Table 3: Base Case Assumptions

1950 Nonrenewable Resource/Production Ratio	146 years
Initial Backstop Price	\$40/bbl (1980\$)
Elasticity of Substitution between Capital and Energy	.75
Retrofit Potential	25%
OPEC Pricing Policy	Constant Real Price to 1983, then adjustment over 1983-1995 to Backstop Price
Energy Price Regulation	Phased Decontrol 1973-1985
Monetary and Fiscal Policy	Non-interventionist

Domestic energy prices are assumed to be regulated between 1950 and 1973. Under regulation, prices are based on historical costs and "normal" profit and do not respond to supply and demand pressures. Starting in 1973, domestic energy prices are gradually deregulated and allowed to move to a market-determined level based on marginal costs and market forces. Deregulation is assumed complete by 1985, the current target for final decontrol of natural gas. By the end of 1980, deregulation is two-thirds complete.

Monetary and fiscal policy is assumed to be non-interventionist. The government is not allowed to run a deficit and growth in the money supply is indexed to growth in real GNP. As a result, the model does not reproduce the inflation of the 1970s.

The model is started in 1950 providing three decades of simulated historical experience. [25] Comparison of simulated and actual behavior establishes the model's ability to capture trends and turning points in important quantities. Because the historical data were not directly used to estimate the model, the simulated behavior is analyzed as if it were a forecast outside the period of fit. In particular, the root-mean-square-percent error and Theil inequality statistics are used to quantify the magnitude and nature of the errors. The Theil statistics decompose the root-mean-square error into three components which measure the fraction of the error due to (1) bias, (2) unequal variation in the simulated and actual series, and (3) unequal covariation in the two series. [26] Of the eleven variables examined (Table 4) only real energy price, energy imports, and real investment exceed 10% root mean square percent error; five are under 5%. Error decomposition shows that except for real energy price, the bias or systematic component of error is 2.5% RMSPE or less. Except for net energy consumption, the unequal variation term is 2.0% RMSPE or less. The systematic errors in energy price, investment, and net energy consumption are readily explained by simplifying assumptions. [27] In interpreting the statistical results, it must be remembered that only three exogenous time series are used: population, technology, and the OPEC price. The ability of the model to capture trends and turning points is therefore primarily due to the endogenous interaction of model elements.

5. Base Case Results: Economic Vulnerability

The past decade has forcefully demonstrated the dangers to both economic stability and national security of heavy reliance on imported energy. Vulnerability, however, is not measured by imports alone. Important indicators of economic vulnerability, all endogenously generated by the model, include:

1. The fraction of total energy supplies imported
2. The real price of energy
3. The fraction of economic output devoted to energy production
4. OPEC revenues and ownership of U.S. assets
5. The duration of the energy transition
6. Reductions in economic growth due to energy.

Table 4: Summary of Historical Behavior of Model

Theil Inequality Statistics*

Variable	RMS Percent Error (%)	Bias	Unequal Variation	Unequal Covariation
Real GNP	3.2	0.3 (10%)	0 (0%)	2.9 (90%)
Real Consumption	4.7	2.5 (54%)	1.4 (29%)	0.8 (17%)
Consumption Fraction**	3.6	1.7 (46%)	0.04 (1%)	1.9 (53%)
Real Private Investment	11.7	0.2 (2%)	1.2 (10%)	10.3 (88%)
Real Wage	5.4	0.5 (10%)	1.3 (23%)	3.6 (67%)
Workforce Participation Fraction	2.5	1.9 (75%)	0.4 (17%)	0.2 (8%)
Total Energy Consumption	4.0	0.2 (4%)	0.2 (4%)	3.7 (92%)
Total Energy Production	7.6	1.1 (15%)	2.0 (26%)	4.5 (59%)
Energy Import Fraction***	13.9	1.7 (12%)	0.1 (0.6%)	12.1 (87%)
Real Energy Price	14.0	8.1 (58%)	0.0 (0%)	5.9 (42%)
Net Energy Consumption	9.7	1.6 (16%)	6.0 (62%)	2.1 (22%)

* Totals may not add due to rounding.

** Real consumption/Real GNP

*** Computed from 1960 to 1977

The fraction of total energy supplies imported directly measures the vulnerability of the economy to sudden price hikes and interruptions in the flow of imports. The duration and magnitude of import dependency defines the "window of vulnerability" facing the nation. Energy production and consumption in the base case appear in Figure 4. Growth in energy consumption slows rapidly after 1980. Consumption rises only 4 quads per year between 1980 and 1990, remains virtually constant at about 84 quads per year until 2000 and then drops to 64 quads per year in 2015 before recovering. Energy consumption grows 4.8 times from 1950 to 2050 while GNP grows 10.6 times. As a result of deregulation, nonrenewable energy production, after stagnating during the 1970s, grows rapidly through the 1980s. The resurgence of nonrenewable production and the near-constant demand for energy combine to reduce imports dramatically from a peak of 21% of total consumption to just 3%. Continued depletion causes nonrenewable production to decline after 1995 as investment in energy shifts to backstop sources. Backstop production is slow to develop, however, and fails to pick up the slack left by depletion: despite average annual growth of over 10% per year between 1990 and 2020, backstop energy supplies just 4.6% of consumption in 2000 and 48% in 2020 even though total energy consumption drops during the period. As a result, imports grow rapidly to a second peak of 26% and remain above 10% until 2035.

The real price of energy (Figure 5) overshoots the initial price of backstop energy by more than 100%, reaching a peak of \$85 per barrel (1980 dollars) in 2010. The overshoot begins around 1995, and the average price remains at least 20% above the initial backstop price until 2030.

The sharp increase in energy prices induces massive conservation and substitution. The energy/GNP ratio falls over 50% between 1980 and 2050, a reflection of the high substitution potential assumed in the base case. During the period of highest energy prices, the ratio falls by over 60%. However, the improvement in efficiency takes time: energy prices reach and then exceed their long-run level by 1997, yet the energy/GNP ratio in 1997 has fallen only one-third of the way to its final value. The delay in the adjustment of energy demand to prices implies the share of GNP and consumption devoted to energy will overshoot its final equilibrium during the adjustment period, magnifying the economic impact of the price overshoot.

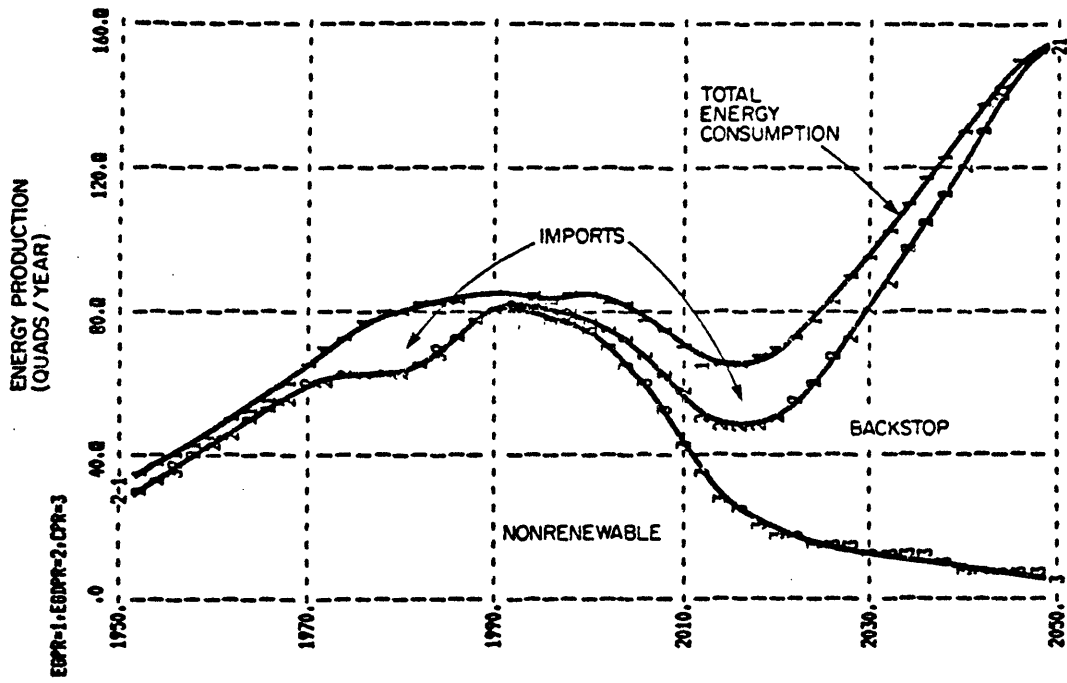


Figure 4: Energy Production and Consumption

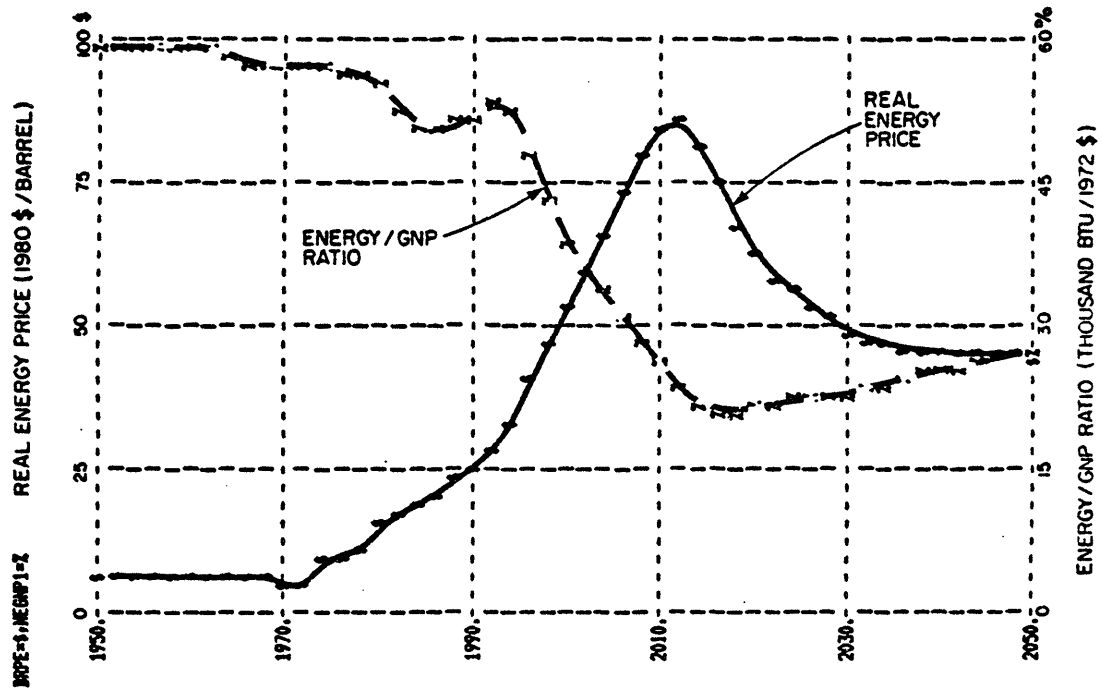


Figure 5: Real Energy Price and Energy/GNP Ratio

The sources of the overshoot in real energy prices are shown in Figure 6. Before 1973, both OPEC and nonrenewable energy prices are stable and roughly equal. Backstop energy is not being produced but would sell at \$40 per barrel (1980 dollars), the assumed initial price. After 1973, the average energy price begins to rise with depletion, deregulation, and the sharp increase in OPEC prices. Nonrenewable energy prices rise rapidly after 1985.

Most striking, however, is the large increase in backstop energy price beginning around 1973. Backstop energy, though not subject to depletion, escalates in price to a peak over \$90 per barrel in 2005. OPEC prices rise to the backstop price between 1982 and 1995 as OPEC adjusts its price to their perception of the price of alternatives. The escalation in backstop prices delays investment in backstop technologies, forcing continued reliance on nonrenewable energy: nonrenewable energy remains less expensive than backstop sources until after 2010. Had the backstop price remained constant, the crossover would have occurred around 1997. The escalations thus directly delay the transition by 15 years. In addition to the overshoot of backstop prices, the average price of energy overshoots the backstop price itself. The long construction delays for backstop force reliance on nonrenewable energy even after it becomes more expensive.

The overshoot of real energy price adds to vulnerability in several ways. First, OPEC's ability to raise oil prices depends on the cost and availability of alternative supplies. The greater the overshoot of domestic energy prices, the greater OPEC's leverage over world prices. Second, the overshoot in real energy price indicates the relative inflexibility of both energy demand and supply in the intermediate-term adjustment period. A large price overshoot therefore indicates long delays and great inflexibility in the development of both alternative supplies of energy and energy-efficient industrial and residential infrastructure.

The fraction of the gross output of the economy devoted to energy production measures the degree to which the productive resources of the economy must be diverted from capital formation (hence reducing economic growth) and from production of goods and services (hence reducing consumption and government activities). Historically quite low, the fraction of economic output devoted to energy (Figure 7) rises to a peak more than six times the

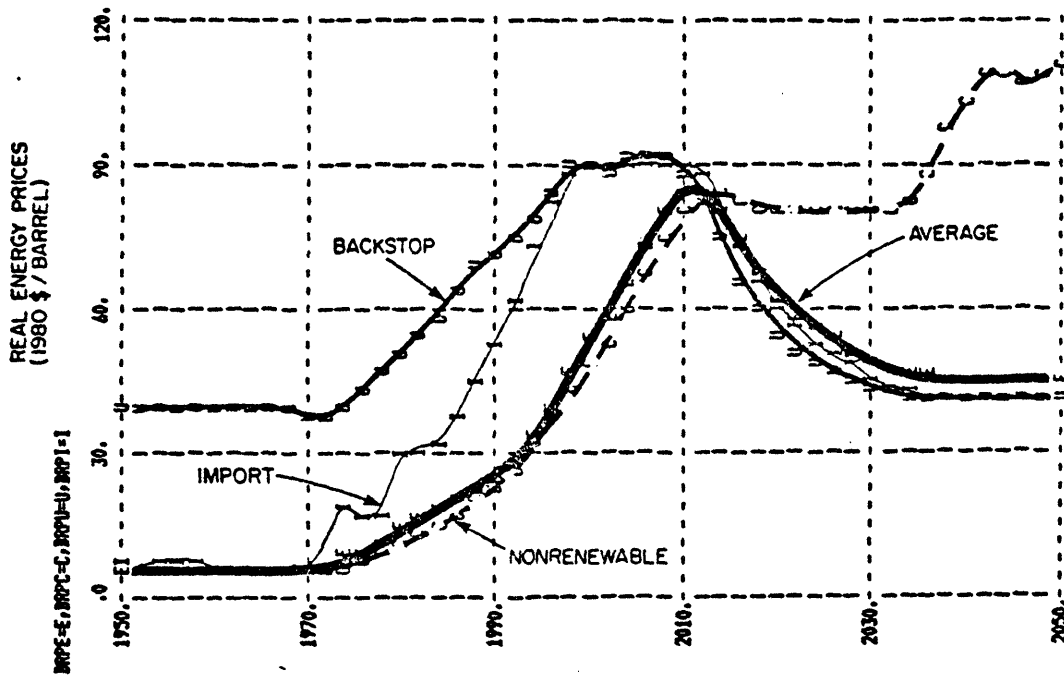


Figure 6: Real Energy Prices

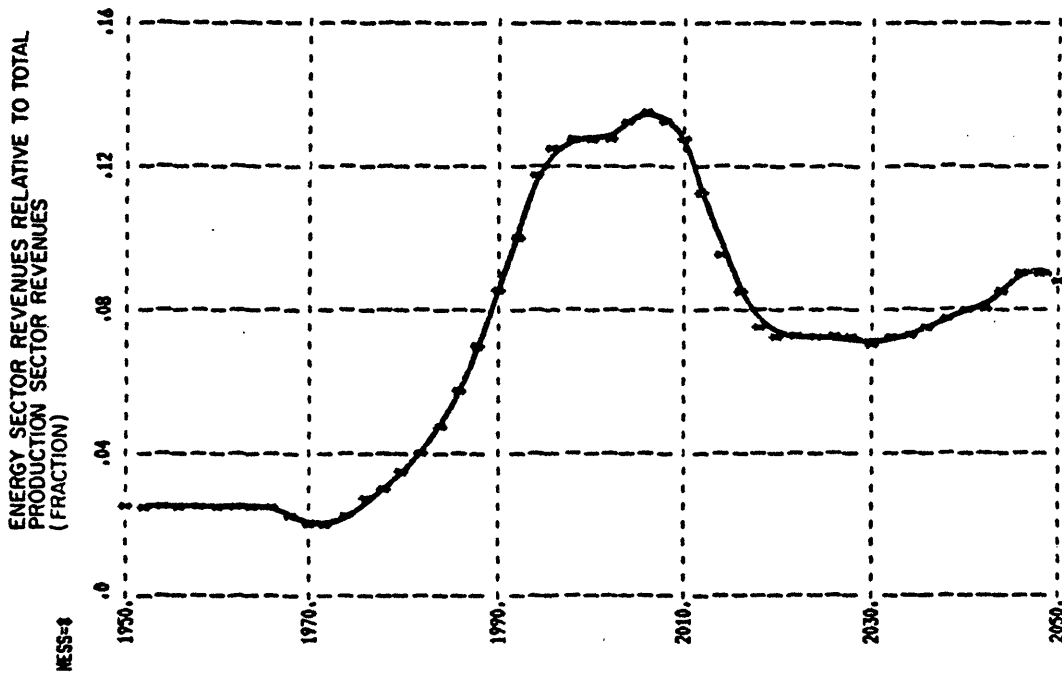


Figure 7: Fraction of Gross Output Devoted to Energy

1970 value and more than 50% of the final value. The relative expansion of the energy sector indicates proportionate contractions in the goods, capital, and government sectors of the economy. The large overshoot in the relative size of the energy sector, due to the overshoot of real energy prices and slow adjustment of energy efficiencies, indicates the greatest stress on the economy occurs during the transition years 1990 to 2015.

OPEC revenues and ownership of U.S. assets directly indicate vulnerability. The flow of revenue to OPEC constitutes claims on the output and assets of the U.S. economy, worsens the balance of trade, places downward pressure on the dollar, and indicates the political leverage OPEC can exert over corporate and national policy. [28] Real OPEC revenues (Figure 8) show the historical period of rapid growth during the 1970s, followed by a decline as imports fall with higher prices during the 1980s. OPEC's revenues rise again to a peak of over \$300 billion per year (1980 dollars) after declining nonrenewable energy production and slow development of backstop sources combine to restore massive dependence on high priced imports.

Reductions in economic growth (and attendant unemployment) increase the vulnerability of the economy both domestically and in international markets. Figure 9 shows simulated real GNP in the base case compared to a simulation in which no depletion occurs. When no depletion occurs, real energy prices remain constant at the initial level. In both runs there is substantial economic growth, due to assumed population growth and technical progress. Consistent with the results of equilibrium energy-economy models, depletion has little long-run effect on GNP: after 2030 the two paths are virtually identical. During the transition period from 1980 to 2030, however, GNP is noticeably reduced by depletion. The reduction is greatest between 1984 and 1994, a ten-year period of no growth. GNP in 1990 is 14% below the no-depletion case. At a 5% real discount rate, the present value of lost GNP after 1980 is \$4.2 trillion or over 9% of the present value of real GNP between 1980 and 2050.

The strong intermediate-term impact of depletion on economic performance is reinforced by real consumption per capita, which falls 7% between 1985 and 1990; in 1995, per capita consumption is still 2.2% lower than the 1980 level. Household expenditures on energy more than double between 1970 and 1995, further reducing non-energy purchases of housing,

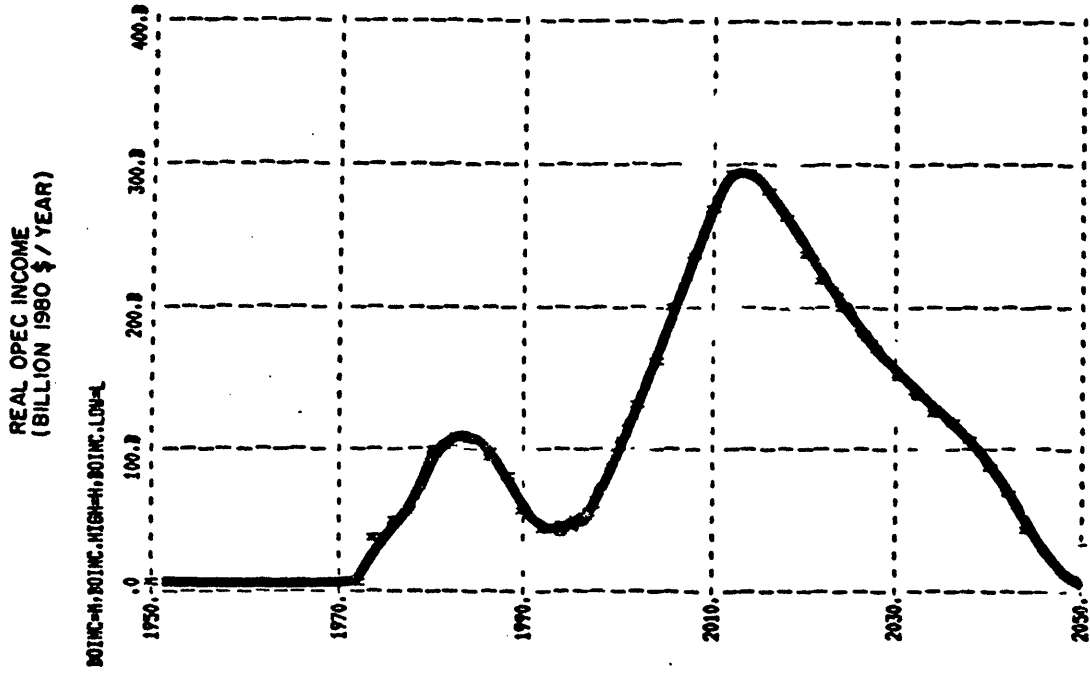


Figure 8: Real OPEC Revenues

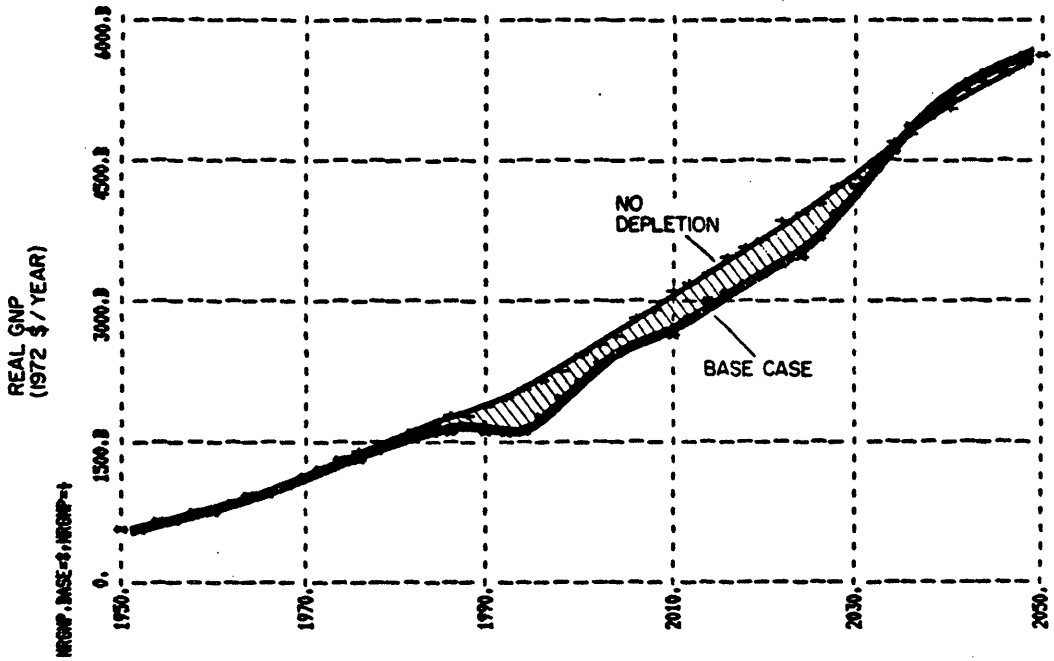


Figure 9: Real GNP Compared to "No Depletion" Case

- c. The economic stresses caused by depletion further slow the adjustment of energy use to optimal levels by reducing the resources available to finance retrofits and investment in efficient capital and housing.
3. Real energy prices overshoot their long-run level, primarily due to escalation in the price of backstop sources. The escalation delays the development of backstop sources, increasing import dependence
 - a. Long construction delays and financial stress lead to a shortage of capital in the backstop sector. To speed construction and boost output, more labor is employed, but at sharply diminishing returns. Costs rise as the industry moves up its short-run supply curve.
 - b. The backstop sector's labor requirements expand faster than the workforce, forcing wages in the sector above the national average.
 - c. The credit-worthiness of the backstop industry declines because long lead times and rising input costs lead to low liquidity. Lenders impose an additional risk premium and reduce the availability of external financing.
 - d. As energy prices rise, so do backstop construction and production costs. Backstop energy technologies are energy-intensive. The greater the energy intensity, the lower the net energy yield of the technology and the greater the escalation of energy prices.
 - e. Backstop energy industry production capacity (constrained by long construction periods and low liquidity) lags orders, and market pressures force backstop prices above costs.

6. Policy Analysis

The model can be used to test a broad range of policies including investment tax credits and accelerated depreciation for backstop energy sources, subsidies and price supports for energy development, and accelerated conservation and retrofits of existing capital stocks. The policies analyzed below focus on the effects of subsidies for different types of alternative energy technologies.

Subsidies for development of backstop energy technologies have been an important component of energy policy to date. The federal government has supported research and development, funded demonstration projects, and most recently, authorized the expenditure of up to \$88 billion for synthetic fuels through the U.S. Synfuels Corporation. The rationale for such subsidies is to speed the energy transition by bringing backstop energy sources on line more

goods, and services. Unemployment is increased by depletion during the transition years by a maximum of eight percentage points over the base case.

Analysis of the base case behavior reveals three fundamental sources of the large intermediate term economic effects of depletion. The major structural causes of the economic impacts, listed below, were identified through sensitivity tests. For example, the role of the long lifetime of energy consuming capital (2a below) was tested by varying the potential for retrofits. Increasing the retrofit potential from 25% to 75%, implying existing capital can be brought 75% of the way from its original efficiency to the efficiency of new plant, equipment, and housing, reduced the peak real energy price by 15% and peak real OPEC revenues by nearly one third, indicating the importance of the delays in replacing old capital with efficient capital. (However, the real energy price, OPEC revenues, and the other indicators of vulnerability still exhibited the modes of behavior of the base case.)

1. Despite a transient increase caused by deregulation, depletion continues to reduce nonrenewable energy production and raise its cost.
 - a. Deregulation increases exploration and production in the near term, but as a direct consequence, depletion of remaining nonrenewable resources is accelerated, reducing production more rapidly in the long term.
 - b. Depletion raises the energy required for discovery and development of nonrenewable resources, reducing the net energy yield of exploration and creating a powerful vicious cycle of higher exploration costs, energy price increases, and higher exploration costs. The "multiplier effect" substantially boosts energy prices above the level required by depletion alone.
2. Energy demand adjusts slowly to rising prices, raising expenditures on energy above their long-run equilibrium value during the transition. More capital and labor are diverted to the energy sector in the intermediate-term than in the long-term, reducing the resources available for consumption and growth.
 - a. The long life of housing and industrial plant and equipment cause average efficiencies to lag the efficiency of new investment by ten to thirty years.
 - b. Delays in perceiving and reacting to changes in the optimal energy intensity of capital further slow the adjustment of energy use to rising prices.

quickly. Developing new energy technologies places extreme cash flow pressure on the firms involved. Subsidies, it is hoped, will establish alternative energy sources on a firm footing, thus allowing the industry as a whole to become self-supporting more rapidly.

Subsidy advocates generally favor particular backstop energy sources over others and see subsidies as a means to foster a particular mix of technologies. To date, subsidies have been heavily focused on "conventional" backstop technologies such as nuclear power, breeder reactors, and synthetic fuels from coal, shale, and tar sands. However, the market may not favor the same ensemble of technologies as the subsidy. Thus there are basic economic questions concerning whether or not subsidies are justified and which types of backstop technologies ought to be subsidized. To test the impact of subsidies, the following assumptions are made:

1. The government provides an unrestricted subsidy to the backstop energy sector, starting in 1982.
2. The subsidy desired by the backstop sector is based on the cash-flow requirements of the sector.
3. The subsidy is financed through proportional reductions in other government activities.
4. Conventional backstop technologies are emphasized.

An unrestricted subsidy based on the cash-flow needs of the backstop sector implies the government provides whatever funds the backstop sector requires but is unable to raise itself through retained earnings or in the capital markets. Financing the subsidy through reductions of other government activities does not alter the total tax burden or government budget, but directs spending away from social and military services.

The emphasis on conventional backstop technologies is crucial. Conventional backstop sources are characterized by long lead times, high capital, energy, and materials requirements, reliance on a specialized labor force, and often, as for example in the case of oil shale, are geographically concentrated in remote areas. [29]

The effects of the subsidy on the indicators of vulnerability are contrasted to a simulation of the conventional backstop technology without subsidies in Table 5. The subsidy reduces the magnitude of vulnerability: the

peak import level is reduced nearly one third, and with it OPEC revenues; real energy prices peak at \$68/barrel rather than \$90/barrel, a reduction in the price overshoot of nearly one-half; market penetration of the backstop technologies is accelerated by eleven years; and economic growth during the transition is improved. The total cost of the subsidy between 1982 and 2020 is \$588 billion, or an average of over \$15 billion per year (in 1980 dollars).

Table 5: Vulnerability Under Conventional and Unconventional Backstop Technologies

Indicator	Test 1: Conventional Backstop No Subsidy	Test 2: Conventional Backstop with Subsidy	Test 3: Unconventional Backstop No Subsidy	Test 4: Unconventional Backstop with Subsidy
Peak Fraction of Energy Imported	27.4%	18.6%	14.5%	7.8%
Peak Fraction of Output for Energy*	13.4%	12.7%	12.3%	12.9%
Peak Real OPEC Revenues (Billion 1980 \$/year)	312	204	137	81
Peak Real Price of Energy (1980 \$/barrel)	90	68	63	54
Duration of Energy Transition**	2034	2023	2024	2020
Present Value of Real Consumption (Trillion 1972 \$)***	36.6	36.9	37.0	37.2
Accumulated Cost of Subsidy in 2020 (Billion 1980 \$)	0	588	0	485

* Payments for Energy/Total payments for factors of production.

** Year backstop sources first supply 75% of primary energy.

*** Present value of real consumption at 5%/year real discount rate.

The subsidy reduces vulnerability and speeds the energy transition both directly, by providing funds needed to construct backstop energy facilities; and indirectly, by reducing the stress on the backstop industry that constrains its development. By providing the financing the private capital markets were initially unwilling to supply, the subsidy eases the liquidity crunch that chronically afflicts the backstop industry (due to its long lead times) and thus makes the industry more attractive to private lenders as well, further easing the cash-flow problem. Reduced financial stress on the backstop industry reduces the escalation of the backstop price, thus speeding the penetration of backstop sources and slowing the depletion of the remaining nonrenewable resources. Slower depletion of nonrenewable resources and reduced escalation of backstop prices lead to the reduction in average energy prices.

Though the subsidy reduces the vulnerability of the economy during the energy transition, substantial vulnerability still remains: imports peak at nearly one-fifth of total energy consumption, OPEC revenues peak over \$200 billion per year, the real price of energy and fraction of gross output devoted to energy production still overshoot their equilibrium values. Further, the subsidy has no appreciable effect on either the fraction of energy imported or the real price of energy until after 2000. The tenacity of vulnerability despite better than a half-trillion-dollar subsidy is fundamentally due to the long lead times, high capital and energy requirements, and centralization of the conventional backstop sources emphasized by the policy. The long lead times and remote locations of the conventional technologies mean the investment and growth rate permitted by the subsidies are offset to some degree as more severe bottlenecks in capital and labor availability are created.

To examine the effects of the emphasis on long lead-time, capital-intensive 'conventional' backstop technologies, a policy emphasizing 'unconventional' backstop technologies was tested. Unconventional backstop technologies, compared to the conventional backstop technologies, are characterized by shorter lead times, lower capital and energy requirements, relative geographic decentralization, and less reliance on highly specialized labor (Table 6).

Table 6: Comparison of Conventional and Unconventional Backstop Technologies

	Conventional	Unconventional
Average Lead Time for Capital (years)	7	5
Capital/Labor Ratio*	70/30	50/50
Energy Intensity** (BTU input/BTU output)	.15	.10
Normal Labor Mobility*** (fraction/year)	.05	.10
Initial Cost (1980 \$/barrel)	40	40

* Initial value share of capital/initial value share of labor.

** Initially. In both cases, energy input per BTU output can vary; the elasticity of substitution is .75 in both cases.

*** Normal labor mobility into the backstop sector. Normal for other sectors = .10/year.

Relative to the conventional backstop technology, the unconventional backstop embodies a lead time two years shorter, a relatively more labor-intensive, less capital- and energy-intensive technology, and is both more decentralized and less dependent on highly specialized labor, reflected in the relative ease of labor mobility compared to the conventional backstop. However, it must be emphasized that the unconventional backstop is not assumed to be inexpensive: the unconventional backstop still requires an average construction period of five years (longer than for nonrenewable energy sources), and capital, labor, and energy intensities are significantly higher than for the nonrenewable energy, goods, and capital sectors. Most important the conventional and unconventional backstop technologies are assumed to have the same initial cost. Thus any differences between the two configurations arise only as a result of their differing technological and geographical characteristics and are not due to assumed differences in costs.

Emphasis on unconventional backstop technologies substantially reduces vulnerability during the transition and speeds the transition as well (Table 5, Test 3). Imports are reduced by nearly 50%, while OPEC revenues fall by more than 50%. The overshoot of the real energy price (and hence the OPEC price) drops from 125% of the long run price to 33%, even though the initial backstop prices in both cases are the same. The penetration of backstop sources of energy is accelerated by a decade compared to the conventional backstop configuration. More striking, development of unconventional backstop technologies with no government subsidies reduces vulnerability substantially more than emphasis on conventional backstop technologies even when subsidized.

Because the unconventional backstop is assumed to have a shorter lead time, the penetration of backstop sources is directly enhanced. However, the assumed lead time is but two years shorter than for the conventional backstop technology, while actual market penetration is advanced fully ten years. The strong synergy is largely due to the effect of the lead time on the financial stress experienced by the backstop sector. Long lead times cause financial problems that further delay development of backstop sources beyond the physical construction period (see 3c above). Shorter lead times reduce the working capital requirements of backstop projects, thus easing the chronic cash-flow problem that afflicts the industry as it pays for construction before facilities can come on line and generate revenues. With better cash flow, the industry is able to expand more rapidly. Further, with the improvement in liquidity comes a reduction in the perceived risk of backstop projects, thus increasing the willingness of capital markets to invest and reducing the risk premium on external financing. Increased availability of less expensive financing further improves the cash-flow of the industry allowing still more rapid development of backstop energy sources.

The reduced capital and energy requirements of the unconventional backstop also contribute to the reduction in vulnerability in two ways. First, reduced capital intensity and increased labor intensity speed development of backstop sources because labor can be acquired more rapidly than capital. Second, reduced energy and capital requirements buffer the backstop sector from the reinforcing cycle of energy price increases, increased costs of plant, equipment and energy inputs, and further increases in prices (see 3d above).

Finally, the assumed ease of attracting and training labor, a reflection of the geographic decentralization and reduced specialization of labor assumed for unconventional backstop technologies, speeds the development of the backstop and lowers its cost by reducing the wage escalation needed to attract the required labor force.

Thus despite the same initial cost, an energy strategy based on unconventional backstop technologies can reduce real energy prices during the transition, improving the performance of the economy more than heavy subsidization of conventional backstop sources.

The reduction in vulnerability deriving from emphasis on unconventional backstop technologies suggests a program of government subsidies directed towards the unconventional technologies would be more effective than subsidies of conventional backstop sources. To test this hypothesis, the subsidy policy discussed above is repeated with the subsidies directed towards unconventional backstop technologies. The assumed policy for subsidizing the backstop sector is exactly the same. The results (Table 5, Test 4) show the subsidy to be much more effective per dollar when applied to development of unconventional backstop technologies. Imports are reduced by nearly half from the unsubsidized unconventional backstop case, while subsidies of conventional backstop technologies reduced the import fraction by only one third. OPEC revenues, already low under the unconventional backstop case, are reduced a further 41% by the subsidy compared to 35% when conventional backstop technologies are subsidized. The overshoot in real energy price is nearly eliminated, as prices peak just \$14/barrel above the initial backstop price compared to an overshoot twice as large when conventional technologies are subsidized. Additionally, though the subsidy of unconventional backstop technologies reduces vulnerability and improves economic performance more than the identical subsidy policy aimed at unconventional technologies, the accumulated cost by 2020 is only 82% as great.

The subsidy is more effective per dollar because the unconventional backstop technologies are less prone to the chronic cash-flow problems and cost escalations that plague the conventional technologies, in which subsidies can be self-defeating to some degree by worsening the capital and labor bottlenecks that constrain their development.

7. Conclusions

The economy is likely to face a prolonged period of economic vulnerability due to the continued depletion of nonrenewable resources, slow development of alternative sources, and lags in the adjustment of energy consumption to higher prices. The magnitude and duration of the vulnerability is strongly influenced, however, by the technological and institutional characteristics of alternative energy sources. If capital- and energy-intensive, geographically centralized technologies with long lead times are emphasized, the economic consequences are likely to be much more severe than those attending the development of relatively labor-intensive, decentralized technologies with shorter lead times, even if the technologies have the same initial costs. Further, government subsidies are much more effective per dollar when applied to the development of unconventional backstop energy sources.

More important, perhaps, than the specific policy conclusions is the demonstration that the feedbacks between energy and the economy and the delays in the adjustment of the economy to the changes wrought by depletion are crucial determinants of both economic behavior and the evolution of the energy sector itself. Neither energy planning nor economic policy can be conducted in isolation from the other, or without consideration of the disequilibrium dynamics of the transition.

NOTES

1. The work described in this paper was supported in part by the U.S. Department of Energy and the California Energy Commission. A detailed description of the model structure, assumptions, and results summarized here may be found in Sterman 1981. The results presented here are the sole responsibility of the author.
2. DOE/EIA 1978a, p. 3.
3. "The easy days of easy and cheap oil are truly over" (Stobaugh and Yergin 1979, p. 13); "Higher energy costs cannot be avoided...[The] environmental effects of energy use are serious and hard to manage." (RFF 1979, p. 4). "...even in the face of increasing demand and higher prices, the production from nonrenewable oil sources will probably level out and peak during the period of 1990 to the year 2000..." (CONAES/SUPPLY 1979, p. 26) The Global 2000 study (CEQ 1980) reached similar conclusions for the world as a whole by examining the global energy problem in the context of population growth, non-energy resources, food, and the environment.
4. On the futility of point prediction, see Forrester 1961, Appendix K.
5. Attributed to Robert Allen by Daly 1977, p. 50.
6. See, e.g., DOE/EIA 1978b, Backus et al. 1979, Cazalet 1977, Carasso et al. 1975, and FEA 1974.
7. DOE/EIA 1978b, DOE 1979.
8. E.g. Hudson and Jorgenson 1974, Hogan and Manne 1977, and Manne 1977. See also DOE/EIA 1979 and Manne et al. 1979 for surveys of energy-economy literature.
9. Hudson and Jorgenson 1974.
10. ETA-MACRO (Manne 1977) and PILOT (Parikh 1976) both assume perfect foresight.
11. Mork and Hall 1979, p. 1.
12. For information on system dynamics, see Forrester 1961, Forrester 1968, Forrester 1980a, Goodman 1974, and Richardson and Pugh 1981. Economic and energy applications include Mass 1975, Naill 1977, Senge 1978, Backus et al. 1979, and Choucri 1981; see also EPRI 1980.
13. For business cycles theories based on the interaction of inventory management and employment policies see Mass 1975 and Low 1980. To the extent inventory/employment dynamics amplify the effects of shocks such as energy price increases, the model will tend to underestimate the short-run effects of the energy transition.

14. Aggregation by heat value implies the various end use fuels are fungible, that is they can be freely substituted for one another. The assumption of fungibility represents an a fortiori simplifying assumption: to the extent actual substitution possibilities among end use fuels are less than assumed, the model will underestimate the likely economic impacts of rising energy prices.
15. The concept of the backstop was introduced by Nordhaus 1973. The Nordhaus model is a linear programming model with perfect foresight and instantaneous adoption of new technologies. A different perspective can be found in Behrens 1973, who examines the problem of substitution to a backstop in a dynamic framework.
16. Solow 1974, p. 4.
17. Griffin 1979, p. 30.
18. Stobaugh and Yergin 1979, Lovins 1977, Sant 1980.
19. The optimization of each sector's factor balance operates on hillclimbing principles, but explicitly accounts for the perception delays in forming expectations of marginal productivity and the physical delays in redesigning and retooling existing products for higher energy efficiencies.
20. For a discussion of the sources of information for and the role of data in system dynamics models, see Forrester 1961, especially Ch. 4.7; Forrester 1980b; and Forrester et al. 1975.
21. See Forrester and Senge 1980 and Richardson and Pugh 1981, section 5.2.
22. The behavior and policy insensitivity of system dynamics models is demonstrated in Forrester 1969, especially Ch. 6 and Appendix B.3, Schroeder 1975, Britting and Trump 1975, Naill 1977 Appendix A, and Meadows et al. 1974. Mass 1974 and Schroeder et al. 1975 include many papers describing the behavior and policy insensitivity of an urban model to both parameter and structural changes.
23. For example, the role of the long lifetime of energy consuming capital was gauged by varying the potential for retrofits to the energy requirements of existing capital. Increasing the retrofit potential from 25% to 75%, implying existing capital could be brought 75% of the way from the original energy efficiency to the optimal efficiency, reduced the peak real energy price by 15% and peak real OPEC revenues by nearly one third. However, the behavior modes exhibited by real energy price, OPEC revenues, and the other indicators of vulnerability were unchanged.
24. Resources: based on USGS and other estimates (Tessmer et al. 1977)
Backstop Price: Lovins 1977 touched off a vociferous debate over the methods and assumptions used in estimating backstop energy costs that is still raging. See also Lovins and Lovins 1980, especially Chapters

- 7 and 8. Rand 1979 documents the problems with cost estimation procedures.
- Elasticity of Substitution and Retrofit Potential: Berndt and Wood 1975 report an Allen partial elasticity of substitution between labor and energy of .65 while that between capital and energy was found to be -3.2 See also Berndt and Wood 1977 and 1979 and Hogan and Weyant 1978.
- OPEC Pricing Policy: OPEC's most likely long-run pricing strategy is to gradually raise the price to the costs of alternative or backstop sources (OPEC 1981). The base case assumes the soft market conditions of 1981 will continue through 1982 resulting in constant real prices until 1983. Between 1983 and 1995, the OPEC price gradually increases to the price of backstop energy. After 1995, the OPEC price equals OPEC's expectation of the price of backstop energy.
25. The simulations actually begin in 1900 from a stationary equilibrium. By 1950, the model settles into a balanced growth path corresponding to the economy of 1950. The 50-year "startup" period is required because the transition from stationary equilibrium to growth involves changes in the age structure of capital and sectoral shifts: relative expansion of the capital sector, changes in workforce participation, savings/consumption decisions, etc.
26. Theil 1966, Ch. 2.3-2.5, esp. pp. 29-32.
27. Investment: The model does not include the business cycle and hence actual investment fluctuates around simulated investment.
Net Energy Use: The model assumes a constant efficiency of energy production and distribution while actual efficiencies have declined with growing electrification.
Energy Price: The model does not include differential technological progress or economies of scale in the energy sector.
28. It is often argued that OPEC ownership of U.S. assets decreases vulnerability by raising OPEC's stake in the performance and stability of the U.S. economy. Such a view, however, presumes revenue maximization (or something similar) dominates OPEC's "objective function", a view both at odds with history and strongly dependent on the precarious stability of member country regimes. OPEC ownership of U.S. assets not only diverts to OPEC income and profit created by U.S. industry and needed for further economic growth, but allows OPEC members to develop sustainable sources of income outside their own countries, both increasing OPEC's latitude for action in the oil market and in internal economic and political policy.
29. The assumptions of the "conventional backstop" case are the same as those for the base case of the model as described in chapters 3 and 4 except for the assumption of reduced labor mobility to the conventional backstop sector.

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