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EXECUTIVE SUMMARY

INTRODUCTION

Oil, as one of the most flexible and portable sources of energy, has become fundamental to the workings of industrial economies. The convenience and previous low cost of petroleum products led to rapid increases in their use for transportation, home heating, electricity generation, and industrial processes. To some extent, the rapid post-war economic growth of the industrialized world was fueled by a cheap and seemingly unlimited supply of oil.

During the decades of the 1950's and 1960's, the world price of oil, adjusted for inflation, gradually declined. However, the relatively stable conditions characterizing the world oil market of the 1950's and 1960's were replaced with the confrontation, chaos, and apprehension of the 1970's. With the 1973 Arab/Israeli war and the deliberate reduction of oil production from Saudi Arabia and other Middle Eastern countries, the world oil price jumped from \$2.50 per barrel in 1972 to \$11.00 per barrel in 1974.

The subsequent world recession and adjustments of oil demand to the higher prices brought a slack world oil market; the oil price declined slowly in inflation-adjusted U.S. dollars and more rapidly in the currencies of other major OECD (Organization for Economic Cooperation and Development) countries. Many U.S. officials, fearing that dramatic declines in the world oil price would inhibit development of substitutes for OPEC oil, concerned themselves with establishing price floors for oil. But following the 1978 Iranian revolution, world oil prices shot up again--this time to over \$30.00 per barrel.

Late in 1980 there were widespread fears that the Iran/Iraq war would fuel yet another price escalation, the third in seven years, but this escalation never materialized. Rather, by early 1981 adjustments of oil

demand to higher prices brought on another "oil glut", and with it, widespread speculation that world oil prices were finally about to fall. The oil price optimism which characterized the mid-1970's again began to dominate popular discussion.

Today, a relatively large share of the world's petroleum continues to flow from the highly unstable Middle East, making it likely that periodic interruptions in the world's supply of oil -- possibly much more serious than those experienced in the past -- will occur. In 1980, 32% of world crude oil production and 42% of WOCA (World Outside Communist Areas) oil came from the Arab members of OPEC. Although the expenditure for oil by OECD nations averages only 6% of their gross domestic product, sudden reductions in oil availability can create havoc for national economies. Thus, the world as a whole is dangerously dependent upon highly insecure oil sources.

The high cost of oil imports, the threat of sudden supply interruptions, and the uncertainty about future oil market conditions pose grave difficulties for the oil importing nations. These problems continue to provide strong motivation for public policy and private sector planning and policy attention. The importance of these issues has motivated this Energy Modeling Forum (EMF) study.

In what follows we summarize conclusions reached by an EMF working group studying the possible future evolution of the world oil market. Members of our group are listed above. In conducting the study, we used ten prominent models of the world oil market to project the possible future evolution of this market under a range of plausible situations.

Our conclusions are based to a large extent, although not entirely, upon results obtained through application of the models to twelve scenarios designed to bound the range of likely future outcomes. One, the Reference Scenario (also referred to as the Reference Case), is given particular atten-

tion as a plausible median case. But it in no way should be interpreted as our "forecast" of the oil future: there are simply too many unknowns to accept any projection as a forecast. The Reference Scenario is meant to be representative of the general trends that might be expected. Many of our conclusions are based upon Reference Case results and upon the variations around that scenario.

OIL MARKET TRENDS

While there remains a high degree of uncertainty about future world oil prices, our analysis suggests that most of this uncertainty concerns not whether real prices^{†1} will rise during the next several decades but rather how rapidly they will rise. An additional uncertainty concerns the duration and magnitude of a short-run decline in prices which began to manifest itself in 1981. We expect a soft oil market during the first half of the decade unless another supply disruption occurs. But by 1990, real prices can be expected to exceed their current high levels. While the trend of real prices will be upward over the next several decades, the pattern could be one either of steady upward price movements or of sudden price jumps followed by gradual and less dramatic declines.

We expect conventional supplies of oil to increase only slowly during the 1980's. Our assumption of relatively constant OPEC oil production capacity and our projections of declining OECD oil production, balanced against moderate increases in oil production from the rest of the world, indicate that in the 1980's the conventional oil production will grow much less rapidly than in the recent past.

By the end of the century we expect significant quantities of unconventional oil production (e.g., oil shale, coal liquefaction, tar sands). When added to conventional production, this will allow high and possibly increasing

rates of world oil consumption for many decades to come.

The rapidly growing economies of OPEC and the oil-importing developing countries can be expected to consume an ever-increasing share of future world oil production unless their economic growth rates are radically reduced. If these nations do increase their oil demands while conventional crude oil production is growing but slowly, we can expect OECD oil consumption to remain roughly constant or decline.

High oil prices will be a major motivating force behind the substitution of natural gas, coal, solar, biomass, and nuclear energy for oil and behind the increased energy conservation in all economic sectors. Industrialization and rapid economic expansion will be the principal factors behind a growth of oil consumption in the less developed countries (LDC's).

Despite the decline in OECD oil use, we expect a continued dependency of the OECD countries upon OPEC oil exports well into the twenty-first century. However, as a fraction of all oil consumption or of all energy consumption by the OECD countries, OPEC exports can be expected to decline significantly. Thus, while the economic problems of vulnerability to supply disruptions may decline by the turn of the century, the problems of high imported energy cost and uncertainty about future conditions will persist.

Lack of dependable information about major determining factors continues to make precise forecasting of oil market conditions impossible. Key uncertainties include the market response of demand and supply to higher prices, the degree of policy induced energy conservation, the economic growth rates of the LDC's and the degree to which balance-of-trade considerations limit their oil imports, the rate of development of alternative energy sources, and the magnitude of future conventional oil and gas discoveries.

IMPACT OF POLICIES ON OIL PRICES

Policies which reduce oil import demand, whether implemented by nations acting alone or collectively, can significantly reduce oil price growth. This effect can be quantified by examining the average price reduction (from what prices would have been otherwise) stemming from each 1 million barrels per day (MMBD) reduction in the quantity of oil imports demanded by the non-OPEC countries. For oil import demand reductions increasing gradually over the next decade, by 1990 we can expect world oil prices to be reduced by between \$0.90 and \$2.40 per barrel (1981 constant dollars) for each 1 MMBD reduction in oil import demand.

During the first three to five years, these import reduction policies generally have a far smaller price impact per barrel reduction, since price adjustments in non-shortage situations tend to occur slowly. Furthermore, over a very long time horizon in which unconventional energy resources become abundant (say by 2010 or 2020), import demand reductions may have little or no world oil price effect since world oil prices may by that time be set by the costs of unconventional fuel production. On the other hand, sudden demand or supply shifts, particularly those temporarily creating shortages, will lead to rapid price changes; the price change per MMBD supply or demand shifts may be several times greater than the \$0.90 to \$2.40 per barrel figure cited above.

Since the OECD together or even the United States alone imports large quantities of oil, import reductions which moderate oil price increases can yield significant economic benefits to these countries. Benefits of import reduction, when expressed on a per-barrel basis, are collectively described as the oil "import premium".

One portion of the import premium is the market power component. This component arises because reductions in imports can be expected to reduce the price paid for all oil imports and, conversely, increases in imports will

cause increases in the price paid for every barrel of imported oil. Thus the economic cost to a country or group of countries for importing another barrel of oil exceeds its price. The amount in excess is called the market power component of the import premium. (The other premium component which we will consider arises from the effect of imports on vulnerability to supply interruptions.)

A simple approximation to the market power component can be based upon the \$0.90 to \$2.40 price impact per MMBD import demand reduction. For a country importing 6 MMBD of oil, the price reduction associated with a 0.5 MMBD demand reduction will be applied to each of the remaining 5.5 MMBD. Thus the market power component of the import premium would be between \$4.95 and \$13.20 per barrel (5.5 MMBD X \$0.90/bbl/MMBD and 5.5 MMBD X \$2.40/bbl/MMBD, respectively). For the entire OECD, importing more than three times as much oil, these figures would be more than tripled.

A more complete analysis of the market power component, taking into account the time patterns of import reductions and price changes, requires the direct use of the models. Here again, a range of estimates has been derived. The median² value of the market power component estimated under our Reference Scenario assumptions is about \$30 per barrel above the world oil price for the OECD as a whole and about \$8 per barrel for the U.S. alone. The magnitude of these estimates provides strong analytical support for energy policy choices which go beyond exclusive reliance on free markets.

SECURITY OF OIL SUPPLIES

Because so much of the world's oil comes from the highly unstable Middle East, the specter of oil supply disruptions remains. In fact, many of us believe that oil supply disruptions larger than those experienced in the past are possible. To examine the implications of such disruptions, we applied the

models to a hypothetical reduction in OPEC production capacity.

Under the assumptions of our Reference scenario, world oil prices increase on the average by \$5 to \$12 per barrel for each 1 MMBD sudden reduction in OPEC crude oil output³, for a disruption approximately twice as large as any experienced to date. However we can expect price jumps to be more than proportional to the size of the disruption: a 1 MMBD disruption alone will increase prices by less than the average per barrel change, an increase in the disruption magnitude from 9 to 10 MMBD will have an incremental effect larger than the average. A 8 MMBD reduction in OPEC production could cause world oil prices to leap upwards by \$40 to \$100 per barrel, resulting in prices exceeding \$100 per barrel. Larger production declines, and consequently larger price explosions, are possible.

Likewise, the economic impacts of supply disruptions could be immense. If the OECD were importing 25 MMBD at the time of the disruption (roughly current levels), the 8 MMBD reduction in OPEC output could lead to increased wealth transfers from the OECD nations to the oil exporting countries of between \$300 to \$1100 billion per year -- 3% to 13% of the combined OECD national products! Unemployment and other macroeconomic consequences of the disruption could multiply these losses several-fold. And "Ratchet effects" which keep prices high long after a disruption imply economic losses will persist even after the disruption itself has subsided.

Although most of our models project large effects of a 10 MMBD capacity disruption, the maximum prices and the price pattern over time vary radically among the various models. There seems to be no consensus among observers of the world oil market as to the character of the price response during a disruption. Too many uncertainties--e.g., stock building and release patterns, expectation formation, exporter behavior--have yet to be resolved.

IMPACTS OF POLICIES ON OIL SECURITY PROBLEMS

Our analysis of price jumps during disruptions suggests that price escalations could be moderated significantly if oil stocks were released or excess capacity were placed into production during the disruption. A 1 MMBD stockpile release would be equivalent in many ways to a 1 MMBD reduction in the magnitude of the oil supply interruption. For a large disruption, price jumps might be moderated by around \$20 per barrel if 1 MMBD of stockpiles were released or excess capacity were put into production. Thus, useable excess capacity or stockpiles could provide major benefits to the oil importing nations.

Gradual import reduction programs taken in advance might also lead to increases in excess capacity and may thereby reduce the price escalation and economic costs of disruptions. Programs could include, among other options, oil tariffs, incentives for energy conservation or supply increases, or fuel switching regulations. Such import demand reductions may moderate disruption costs in two ways. Under a regime of OPEC administered prices, import demand reductions are met partially by OPEC production declines and consequent increases in excess capacity. To the extent this occurs, the price escalation during a disruption may be moderated. In addition, a reduction in the quantity of oil imports exposed to the price escalations further reduces the economic impacts. For example, a 5 MMBD demand reduction undertaken prior to our hypothetical 10 MMBD oil supply disruption could reduce its economic costs by 30% to 90%.

When expressed on a per-MMBD basis, this disruption-related economic benefit is referred to as the "security component" of the import premium. In our estimations, the security component, although important, is generally much smaller than the market power component. Under our Reference Case assumptions, security component estimates range from \$1 to \$5 per barrel for the

U.S. These values depend upon the probability of disruption -- 5% per year -- we have used for the calculations. Higher probabilities, felt by many working group members to be more realistic, would increase the estimated security component. In addition, because we have been unable to include the macro-economic losses associated with unemployment induced by oil supply interruptions, our security component estimates should be viewed as lower bounds.

USING THE IMPORT PREMIUM IN POLICY MAKING

Estimates of the oil import premium can be used for evaluating energy policy options, since the premium quantifies the value to the U.S. or to the OECD of reducing oil imports, or, equivalently, the cost over and above the world oil price of increasing oil imports. However, a given premium value does not imply which specific policies are the most appropriate, but only that there is a large value for policy measures which go beyond sole reliance upon free markets.

Estimates of the import premium depend upon a number of unresolved issues -- OPEC nation responses to energy policy choices in the OECD, responses of energy users and producers to changing prices or other incentives, the appropriate discount rates and time horizons for the analysis, oil stockpile release rates and petroleum inventory patterns. Thus the actual premium may be somewhat higher than our best estimates, perhaps by a factor of two or more. Although the premium could be below the low end of our range of estimates, this seems unlikely.

Our estimates of the import premium do suggest several general conclusions about energy policy. Any policy which can reduce imports at a cost less than about \$8 per barrel above the world oil price is very likely to be economically beneficial, while one which costs more than about \$20 per barrel above the world price is likely to result in net economic losses to the

U.S. economy. Those which lie in between cannot be evaluated with any confidence using our results. However, our analysis does lead to the unmistakable conclusion that some import reduction policies going beyond simple reliance upon free markets can be justified by their economically beneficial impacts on world oil markets.

THE TRANSITION TO OIL SUBSTITUTES

The preceding discussion focuses on the next two decades or so. Beyond this time, far-reaching changes in the world oil market may begin to manifest themselves. This study has made no attempt to resolve the great controversy which surrounds the issue of which energy future is most desirable. Rather, we have focussed on the oil market effects of different assumed unconventional fuel supply levels (here referred to as "backstops") under plausible assumptions about future oil demand and conventional supply.

Under our assumptions about cost and future supply of backstop oil (by definition, a perfect substitute for oil, expensive, but inexhaustible), the world oil price rises well above average backstop costs in most circumstances. Massive quantities of backstop production (perhaps as large as the current level of WOCA oil production) are required before world oil prices decline to backstop costs. While backstop technologies may not place a cap over world oil prices during the next thirty years, generally the greater the quantity of backstop production, the lower the world oil price. Similarly, the greater the quantities of natural gas or other oil substitutes which are available, the lower the world oil price. These price differences can be large. By 2020, projected world oil price is reduced (on the average) between \$1.20 and \$3.90 per barrel for each 1 MMBD increase in backstop production rates.

Oil prices over the medium term (to 2000) will depend upon the beliefs held by oil producers and consumers as to the future cost and availability of

backstop oil. If consumers expect a technological breakthrough, and with it lower oil prices, they will less aggressively install energy-efficient capital equipment. As a result oil demand and prices may be higher than otherwise. Conversely, if conventional oil producers expect the breakthrough, they may hasten oil production in search of higher profits before the breakthrough occurs. Lower oil prices in the medium term may result.

No attempt was made to estimate the costs associated with increasing the supply of alternative fuels. Thus, our results provide no comparison of costs and benefits. The study does indicate, however, that changes in backstop availability can significantly influence the national and international distribution of wealth between producers and consumers. In particular, countries producing backstop oil may reap large profits, to a large extent at the expense of OPEC revenues.

THE STATE OF THE ART OF WORLD OIL MODELING

In utilizing the ten models of the world oil market, we have also reached a number of conclusions about the current generation of models. The ten models use a striking diversity of assumptions and approximations. They differ in their degree of product coverage and disaggregation, with some representing oil markets only, ignoring other energy markets, others representing oil markets within the context of all major energy commodities, and still others treating all energy as a single broad aggregate.

The models differ widely in their treatment of OPEC decision making. In some, virtually all OPEC choices are exogenous. In others OPEC is treated as an optimizing monopolist while in still others, rules-of-thumb for OPEC decision making are simulated. The diversity of these assumptions reflects limitations on current scientific knowledge and suggests that additional research on OPEC behavior is called for.

The models differ, although less fundamentally, in their representation of oil demand. All but one assume that demand responds slowly to price: short-run price elasticities[†] of demand are far smaller than long-run elasticities. Only four models include any effect of oil prices on economic activity, even though the existence of such an effect is well established. Even those models which represent this feedback from oil prices to economic growth do so using simple formulations.

None include considerations of international balance of trade or represent the consequences of trade imbalance for economic growth or for oil import demand. Finally, none include the macroeconomic losses associated with unemployment of labor and capital equipment during a severe disruption of oil supplies.

The differences and admitted limitations of the models reflect the current imperfect understanding of the world oil markets. It should be remembered that the oil market is a highly complex, uncertain network of centralized and decentralized decision making processes. Decisions are made in OPEC member nations, in Rotterdam trading rooms, in legislative bodies of the oil importing countries, in oil companies, and in the homes and work places of individual users of oil. Political shifts, changes in weather, war and revolution may cause rapid, unforeseen changes in oil market conditions. Fundamental research into these markets remains to be done before we will be able to analyze world oil markets as well as we are able to analyze domestic markets. To the extent that domestic policy and planning decisions require information about world oil trends and options -- and we believe such information is crucial to the entire energy debate -- more research, modeling, and analysis should be directed toward the world oil and energy markets.

THE STUDY DESIGN

The Energy Modeling Forum (EMF)⁴ pursues two goals related to the use of models in energy analysis: to improve understanding of the models themselves and to utilize existing models to improve understanding of current energy issues. These goals are pursued by identifying a number of models constructed for similar purposes, comparing the assumptions on which they are built and the results they produce, and applying these models to current energy policy and planning issues.

In this study we have used mathematical models as tools for predicting and explaining what might happen in the world oil market, but only under a specified set of conditions. These models require as inputs many assumptions about real world relationships. In addition to the specific numerical assumptions needed, the projections are shaped by decisions about what to leave out of a model. Such specific features as an endogenous determination of OPEC production capacity and capacity utilization, or broad considerations such as the international political forces and potential changes in consumer life style may often be omitted. The extent to which the results accurately predict the future behavior of the world oil market depends critically upon the accuracy and completeness of the assumptions included and the significance of those phenomena excluded. Therefore, no model results can be considered perfect forecasts of the future. A detailed analysis of the underlying assumptions, as is attempted here, is necessary to sort out the often contradictory projections from different models.

Dependence upon assumptions and consequent uncertainty in projections are characteristics not only of the mathematical models but also of the mental models used by experts or groups of experts to assess future oil market conditions. There is no alternative in energy analysis to some form of rational evaluation, involving many explicit or implicit assumptions.

Mathematical modeling is often a convenient, explicit, and powerful vehicle for such thinking.

This report summarizes conclusions reached by an EMF working group studying the possible future evolution of the world oil market. Many of the conclusions result from insights gained through the use of models; but they do not represent an uncritical acceptance of the numerical outputs from models.

The 45 working group members, drawn from government agencies, private sector firms, consulting and research institutions, international organizations, and universities, included both modelers and non-modelers. The group as a whole met four times between early 1980 and early 1981; the EMF staff assisted the working group throughout the study.

This document is a summary of our conclusions. The complete report will be published separately.⁵

THE MODELS

Table 1 lists each of our ten models, the working group member representing that model, and the organization with which the model (or the modeler) is currently closely associated. With the exception of the model designed by Salant, which was run independently by ICF, Inc., models were run by or under the direction of those individuals listed in Table 1. All runs were made by people having intimate knowledge of the specific models. Most models were run for nearly all scenarios.

In this section we outline the key assumptions incorporated into these models (as used in this study). There are essentially three sets of differences across the models. First, the models may be based upon different assumptions as to what real-world relationships are important to include in the model and which can be safely ignored. Second, modelers may disagree about the proper form for modeling the same real-world relationships.

Table 1
The Models

<u>Model</u>	<u>Representative</u>	<u>Organization</u>
Gately/Kyle/Fischer	Dermot Gately/John Kyle	New York University/ Imperial Oil
IEES/OMS (International Energy Evaluation System/ Oil Market Simulation)	Calvin Kilgore	U.S. Dept. of Energy
IPE (International Petroleum Exchange)	Nazli Choucri	MIT
Salant/ICF	Stephen Salant William Stitt	U.S. Federal Trade Commission/ ICF, Inc.
ETA-MACRO	Alan Manne	Stanford University
WOIL	John Stanley-Miller	U.S. Dept. of Energy
Kennedy/Nehring	Michael Kennedy/ Richard Nehring	University of Texas/ RAND Corporation
OILTANK	Leif Ervik	Christian Michelson Institute
Opeconomics	John Mitchell	British Petroleum Corp.
OILMAR	Frank Potter	Energy and Power Sub- committee: U.S. House of Representatives

Finally, differences in the numerical parameters used within a given form are possible. In what follows we will discuss only the structural differences, i.e., the differences in the features included and in the fundamental ways these features are represented.

Model Types

All models of the world oil market include, at least implicitly, the behavior of three sectors, or sets of participants: oil (or energy) consumers, non-OPEC oil (or energy) producers, and OPEC oil producers. In constructing a model, two basic questions must be answered: (1) How does each sector behave? and (2) How are the choices coordinated among sectors to maintain supply-demand balance in the market? The ten models we have used represent a range of different answers to these questions. The differences and similarities in modeling approaches are summarized in Table 2 and will be discussed briefly in what follows.

The models can be divided into two broad categories: seven recursive simulation models--IEES/OMS, OILMAR, WOIL, Gately/Kyle/Fischer, IPE, OILTANK, and Opeconomics--and three intertemporal optimization models--ETA-MACRO, Kennedy/Nehring, and Salant/ICF. Recursive simulation models are those in which decisions of the various actors are assumed to depend upon information only about past and current events (or information based upon simple extrapolations of past changes.) In the intertemporal optimization models at least one sector is able to take into account information about future events. Typically this is made possible by assuming that actors have perfect foresight and that they make current decisions so as to maximize explicitly a discounted sum[†] of current and future benefits.

Although the difference between these two model types is important philosophically and explains a number of differences in results (as will be

Table 2

SUMMARY DESCRIPTION OF 10 WORLD OIL
MARKET MODELS AS IMPLEMENTED IN EMF 6 STUDY

Features	Models				
	IEES/OMS	OILMAR	WOIL	Gately/Kyle/Fischer	IPE
Model Type	recursive simulation	recursive simulation	recursive simulation	recursive simulation	recursive simulation
Foresight	none	none	none	none	none
Regional Aggregation	all EMF OECD regions, OPEC, and LDCs	U.S., OPEC, and rest of WOCA	U.S., other OECD OPEC, Mexico, and other LDCs	OPEC and WOCA	8 production and consumption regions
OPEC Production Capacity	exogenous	exogenous	exogenous	exogenous	endogenous, based on expected future demand
Price or Quantity Determination	price reaction ¹ function	price reaction function	price reaction function including expected future capacity utilization; costs	price reaction function including capacity utilization at time T-1	price reaction function including R/P ratio; costs, exogenous royalties
Consumers Direct ² Price Influence on Demand	via crude-price elasticities	via crude-price elasticities	product-price response via capital stock	via crude-price elasticities	via crude-price elasticities
Energy-GNP Feedback	one-parameter feedback in OMS; other adjustments in econometric models	not included	one-parameter feedback with short lag	not included	not included
2/3 Adjustment Time (Years)	5	5	10; depends on actual GNP	14	5
Oil vs Total Energy ³	OMS is oil-only, but explicit fuel switching occurs in IEES	oil only	several energy forms are considered	all energy demands and non-OPEC supplies are aggregated	oil only
Non-OPEC Producers Price Influence on Conventional Supply	via elasticities	none--oil production is exogenous	via investment (U.S.), elasticities (ROW)	via supply curve	via elasticities
Depletion	resource cost curves	implicit in exogenous production path	minimum R/P ratios; resource cost curve for U.S.	none--technological growth may be considered net of depletion	depletion multipliers (except in Egypt and Mexico)
Use of EMF Backstop Quantities	no backstop; time horizon is 1995	upper bounds	upper bounds	no backstop is explicitly identified	base projection

¹ All price reaction functions use capacity utilization at time T as one of the determinants of percent price change from T to T+1; the other explanatory variables are as shown.

² Excluding Energy-GNP feedback

³ This item applies to both the Consumer and Non-OPEC Producer Sectors.

Table 2 (cont.)

Models				
OILTANK	Opeconomics	ETA-MACRO	Kennedy/Nehring	Salant/ICF
recursive simulation	recursive simulation	intertemporal optimization	intertemporal optimization	intertemporal optimization
none	none	OECD consumers plus producers	non-OPEC conventional oil producers	OPEC and non-OPEC producers
16 production and consumption regions	Iran, Saudi Arabia, other OPEC, OECD, LDCs and CPEs	OECD and OPEC	9 production regions; U.S., other OECD, and ROW consumption regions	all non-CPE EMF regions
exogenous (except in high price scenario) price reaction function including capacity utilization at time T-1	exogenous hybrid price reaction function/supply function minimum revenue targets	exogenous price determination function of OECD imports	exogenous exogenous production	exogenous intertemporal optimization to maximize discounted profits
via product-price elasticities not included 10 oil only	via crude-price elasticities one-parameter feedback with long lag approx. 2 demands for several energy forms are aggregated	via intertemporal optimization to maximize discounted utility of consumption aggregate production function for OECD economy 14 pre-2000, 16.4 post-2000; depends on actual GNP several energy forms are considered	via product-price elasticities for old and new capital not included 10-12.3 pre-2000, 12.5-14 post-2000; varies by region oil only	via crude-price demand curve not included 0 oil only
via new discoveries and the recovery factor; oil production occurs at constant R/P ratios constant R/P ratios not used; production depends on price via investment	oil production is exogenous; oil price affects only coal and natural gas production implicit in exogenous production path included exogenously	via intertemporal optimization to maximize discounted utility of consumption resource cost curves base projection	via intertemporal optimization to maximize discounted profits resource cost curves upper bounds	via intertemporal optimization to maximize discounted profits resource cost curves upper bounds

illustrated in our discussions of the transition to new energy sources), it does not explain all or most of the result differences. For this, a closer look at each of the three major sectors included in each model (non-OPEC producers, OPEC producers, and oil consumers) is necessary.

Oil Consumers

The ten models differ in their representation of oil demand: some explicitly consider the oil-using capital stock owned by consumers; others simply use demand functions. However, each can be seen as embodying an oil demand function which indicates at a particular time how much oil will be purchased at a given price; in general, demand decreases with oil price rises and it increases with economic growth. Most of the models include the price elasticities of demand for oil or for energy as exogenous inputs. For these models long-run primary[†] oil demand elasticities were standardized at -0.6 or long-run primary energy demand elasticities were standardized at -0.4, values consistent with previous EMF work⁶.

All of the models except Salant/ICF assume that demand changes slowly in response to price changes.⁷ The implication of this is that short-run price elasticities of demand are far smaller than long-run elasticities.

The models vary as to whether and how they represent the effect of increasing oil prices on the level of economic activity (GNP or GDP). A feedback from oil prices to economic activity tends to reduce projected price fluctuations and price growth rates by increasing the responsiveness of demand to prices: price increases not only decrease demand directly; they also reduce economic activity, which in turn lowers demand still further. Only four models--IEES/OMS, WOIL, Opeconomics, and ETA-MACRO--explicitly include this feedback. This feedback helps explain the relatively low projected prices in these models.

Another significant demand factor, which relates not only to oil consumers but also to the non-OPEC suppliers, is the energy product coverage and disaggregation. Five represent oil markets only, ignoring other energy markets; WOIL, IEES/OMS, and ETA-MACRO represent oil markets within the context of all major energy commodities; and Gately and Opeconomics treat some or all energy forms as perfect substitutes for one another. If energy demand elasticities, rather than oil demand elasticities, are standardized among the models, Gately and Opeconomics approach leads to a more price-sensitive demand for OPEC oil, since OPEC is now the residual supplier out of a larger energy pool, rather than just the residual oil supplier.⁸

None of the models include explicit treatment of the inventory holding policies of the oil consumers, in particular, the rapid build-ups of inventory in times of oil supply disruptions nor the inventory declines (such as are currently being seen) when slack oil markets are expected. Thus they tend to under-estimate price jumps during times of supply interruptions and to over-estimate oil import demand when expectations of tight supplies are being replaced by expectations of slack markets.

Non-OPEC Oil Producers

The modeling approaches for projecting conventional oil production vary widely.

IEES/OMS, WOIL, Gately, and IPE use explicit supply curves, except for the U.S. region in WOIL, which responds via investments in capital. All four incorporate slow adjustments of supply to price changes. In OILMAR and Opeconomics, non-OPEC conventional oil production is an input. In OILTANK, non-OPEC oil is produced at a constant reserve/production ratio; prices have a lagged impact on new discoveries.

All of the intertemporal optimization models project non-OPEC supply as

the result of an intertemporal optimization problem: In Kennedy/Nehring and Salant/ICF, the objective is to maximize the discounted sum of profits for oil producers, while in ETA-MACRO, consumers decide how much to invest in oil production so as to maximize the discounted utility of consumption. In Kennedy/Nehring marginal extraction costs increase with extraction rates; the Salant/ICF model was run by ICF assuming constant marginal extraction cost up to a maximum rate of production.⁹

Those models in which non-OPEC production is set exogenously (and is therefore independent of price) can show high or low prices in comparison to other models, dependent upon the precise levels assumed. Our analysis indicates that these and other non-OPEC supply factors, such as resource base or foresight assumptions, are important contributors to the observed differences in price projections.

The study design specified the production cost of backstop oil and the maximum quantities available in each year, but the modelers differed in how they interpreted those quantities. In Opeconomics, backstop quantities are included exogenously; in OILMAR, WOIL, Kennedy/Nehring and Salant/ICF, they are regarded as upper bounds, met only under favorable oil price conditions. In ETA-MACRO and IPE, the study design backstop quantities serve as a base projection, with actual production lower or higher depending on oil prices and profitability. OILTANK was run disregarding the limits specified in the study design. In OILTANK, production depends only on investment, which in turn depends on oil prices. No backstop is explicitly identified in the Gately model. IEES/OMS results extend only to 1995 and hence include no backstop.

OPEC Oil Producers

The decision by OPEC nations as to how much oil production capacity to maintain is generally treated quite simply. Nine of the models are run with

OPEC production capacity specified exogenously, using quantities indicated in the study design. Only IPE determines capacity endogenously, with desired capacity a function of expected (although not necessarily realized) future demand.¹⁰ In each of the models, OPEC production can never exceed capacity.

The ultimate decision for OPEC -- what quantity to sell or what price to set (but not both) -- is represented in various ways within the models. In models which treat OPEC as setting the world oil price, OPEC producers supply whatever quantity is demanded at that price (subject to its capacity constraint); in models which treat OPEC as setting a production level, some market clearing mechanism is used to find the price at which total supply from all sources is equal to demand. This difference is primarily based upon the technical details of the computer algorithms and makes little difference in the resulting projections.

One model -- Salant/ICF -- incorporates the assumption that OPEC maximizes a discounted sum of profits as an omniscient monopolist. In such an optimizing model, production in any year depends upon expected future demand for oil and characteristics of the demand function. In Kennedy/Nehring, price is found so as to balance total supply and demand, except that in this case OPEC production is set exogenously as an input by the modeler, rather than as a result of an optimization. In ETA-MACRO, OPEC price in any year is determined by OECD imports during that year, with greater imports associated with greater price¹¹. In Gately, OPEC nations are seen as groping toward some long-run optimal pricing policy, operating as monopolists with imperfect information.

In all of the recursive simulation models, OPEC sets a price for its oil in each year, supplies as much as it can at that price and then uses its degree of capacity utilization in setting the price for the following year. this procedure implies that the short-run OPEC supply is perfectly elastic up

to the capacity limit and therefore that a reduction in demand for a given year will have no effect on that year's price but will only result in a smaller increase or a greater decrease in price during the following years.

Six of these seven recursive simulation models use "price reaction functions", in which the OPEC pricing policy is to attempt to maintain capacity utilization at a certain desired level, typically 80 to 90 percent. Capacity utilization above the desired level results in price increases and utilization below, in price decreases. Prices generally are allowed to fall far less rapidly than they can rise. As discussed more fully in a subsequent section, a consequence is that OPEC requires time to regain equilibrium after a disturbance and oscillatory behavior may occur while OPEC tries to regain its desired capacity utilization.

Summary

The analytical tools we used are not primarily models of OPEC decisionmaking but rather models of the world oil system. Only one provides estimates of OPEC capacity as an output; the rest require this central OPEC choice variable as an input. However, most of the models do treat OPEC production choices. To the extent OPEC decisionmaking is represented, economic paradigms are used. Little attention is paid to the internal structure of OPEC or to the political factors impinging upon the OPEC nations. However, the models do allow evaluation of the influence on world oil markets of production or pricing decisions made by OPEC as a whole, although they do not allow reconciliation of the many theories of OPEC behavior.

While the models vary greatly in their structural characteristics, they have very important commonalities. Each includes representations of oil supply and demand. Each includes some representation of the world oil price setting mechanisms. And each assumes that, over time, markets will tend to

adjust so as to equate oil supply and demand on a world-wide basis. But beyond these fundamental commonalities, the structures of the models vary radically.

The variations in the model structures imply differences in the projections obtained with the various models, as will be apparent in what follows. This does not mean that their results cannot be useful to policy makers and analysts. As we will show in later sections of this report, even with the great differences in the models, we have been able to reach conclusions which are robust across all of the models deemed to be appropriate for the various issues. In addition, the process of analyzing the differences in results can prove useful for delineating the major issues and for focusing attention on the implications of alternative assumptions, alternative assumptions not only in the models but also in the minds of experts and policy-makers.

THE SCENARIOS

In order to address fundamental uncertainties and policy actions, the working group designed twelve alternative scenarios. The twelve include a Reference case plus eleven others, each defined by varying one or more assumptions from those in the Reference case. Some include changes only in the policy assumptions, others only in the resolution of key uncertainties (e.g., economic growth rates, technological progress), and still others in both classes of assumptions.

Each scenario is an abstraction of a class of related issues. Hence a given scenario may represent many different specific situations. For example, many different actions may reduce the demand for oil in the United States: taxes, regulations, subsidies, information campaigns, or technical progress. Increased supply of natural gas, enhanced ability to use coal, or railroad

electrification may likewise reduce oil demand. Because each reduces import demand, for our purpose of estimating world oil market impacts, each could be examined by use of a single scenario which assumes an oil demand reduction at every oil price.

Table 3 lists the scenarios and summarizes their definitions. More complete definitions, including numerical input assumptions, appear in Appendix A (See Table A-4).

Reference Case (Scenario 1)

The Reference (or base) Case, has two purposes: to bring the models into as close agreement as possible on basic assumptions and to provide a reference with which to compare the results of the other scenarios. All other scenarios are derived by varying one or more of the Reference Case input assumptions. The Reference case assumptions include a constant OPEC capacity of 34 million barrels per day (MMBD) and annual GNP growth rates of approximately 3% in the OECD and 5% in the oil importing LDC's through the year 2000.

Oil Demand Reduction (Scenario 2)

This scenario is intended to simulate the effects of a vigorous and successful import reduction program in the OECD. Specific policies represented here could include crude oil tariffs, other energy taxes, mandatory fuel use restrictions, fuel switching incentives, and efforts to increase domestic energy production.

In the Oil Demand Reduction Scenario, the demand for oil throughout the OECD is lowered from the Reference Case values. Total OECD reductions in selected years are 5 MMBD by 1985, 10 MMBD by 2000, and 20 MMBD by 2020.

Table 3
Scenario Descriptions

<u>Scenario</u>	<u>Description</u>
1. Reference	Base case for analyses
2. Oil Demand Reduction	Aggressive import reduction program in the OECD
3. Low Elasticity	Reduction in demand elasticities to 5/8 of Reference case magnitudes
4. Oil Demand Reduction/ Low Elasticity	Aggressive import reduction program in low elasticity world
5. Low Economic Growth	Reduced GNP growth rates throughout the world
6. Restricted Backstop	Reduced (by 50%) availability of non-conventional energy
7. Disruption	Sudden and indefinitely continuing 10 MMBD reduction in OPEC capacity (1985)
8. Technological Breakthrough	Reduced cost and increased availability of non-conventional energy
9. Disruption/ Low Elasticity	10 MMBD OPEC capacity reduction in low elasticity world
10. Optimistic	Aggressive import reduction program; more availability of non-conventional energy; increased OPEC capacity
11. Oil Demand Reduction/ Disruption	10 MMBD OPEC capacity reduction in presence of aggressive import reduction program
12. High Price	Oil price set at 50% higher than values determined in Reference case.

Low Demand Elasticity (Scenario 3)

Although the crude oil price elasticity of demand is a key determinant of world oil prices, no single estimate for this parameter is widely accepted. This scenario examines the sensitivity of model projections to changes in this parameter.

The short-run and the long-run price elasticities of demand for primary energy¹² are reduced from their Reference Case values of 0.04 and 0.4, respectively, to five-eighths of these values. For those models which include only oil, crude oil price elasticities are reduced by five-eighths from their Reference Case values of 0.06 and 0.6.

Oil Demand Reduction/Low Demand Elasticity (Scenario 4)

Scenario 4 combines the assumptions of the previous two scenarios to examine the effects of a vigorous energy conservation program under the lower elasticity assumption.

Low Economic Growth (Scenario 5)

Scenario 5 illustrates the oil market effects of reduced world economic growth.

For the Reference Case and the Low Economic Growth case we standardized the economic growth rates that would occur if crude oil prices were to remain constant at their 1980 levels. For the Low Economic Growth Scenario, those growth rates are reduced to two-thirds of their Reference Case values in all regions of the world. Appendix A displays both sets of assumptions.

Disruption (Scenario 7)

Scenario 7, which illustrates impacts of a substantial and sudden change in OPEC oil production capacity, was designed to allow examination both of long-run changes in production capacity and of sudden supply disruptions.

On January 1, 1985 and thereafter, Middle East OPEC oil production capacity is unexpectedly reduced by 10 MMBD from its Reference Case value of 34 MMBD.

Disruption/Low Elasticity (Scenario 9)

Scenario 9 combines the low demand elasticity of Scenario 3 with the disruption of Scenario 7, to illustrate effects of suddenly reduced OPEC capacity in a world characterized by a low price elasticity of oil demand.

Restricted Backstop (Scenario 6)

Scenarios 6 and 8 examine responses to alternative assumptions about the cost and availability of non-conventional substitutes for oil (such as biomass, coal liquefaction, coal gasification, oil shale, and tar sands). Scenario 6 examines the implications of slow growth in the availability of these substitutes, or "backstop" energy sources. Maximum rates of production of backstop energy are one-half of those in the Reference Case. In the Reference Case, maximum production rates for backstop energy are 1 MMBD in 1996, 5 in 2000, 10 in 2005, 20 in 2010, 27.5 in 2015, and 35 MMBD in 2020. (See Appendix A). In both cases, production costs are \$60 per barrel (1979 dollars), which translates to \$71 per barrel in 1981 dollars.

Technological Breakthrough (Scenario 8)

Scenario 8 examines the impacts of a major advance in energy technology. A perfect substitute for crude oil becomes available in the year 1996 and afterwards at a cost of \$40 (1979 dollars) per barrel, or \$48 per barrel in 1981 dollars. Maximum available quantities through 2010 are identical to those available in the Reference Case. After 2010, the maximum quantities increase to 40 MMBD in 2015 and 80 MMBD in 2020.

Optimism (Scenario 10)

This scenario combines Scenario 2 (Oil Demand Reduction) and Scenario 8 (Technological Breakthrough), with an assumption that OPEC expands its capacity by 1 MMBD in each of the years 1982-1987, a 6 MMBD increase by 1987.

Disruption/Oil Demand Reduction (Scenario 11)

Scenario 11 allows analysis of the degree to which disruption impacts would be mitigated by a pre-existing oil demand reduction or other import reduction program.

The disruption assumptions of Scenario 7 are combined with the oil import reduction assumptions of Scenario 2.

High Oil Price (Scenario 12)

Scenario 12 is designed to examine how oil supply, oil demand, and OPEC revenues depend upon OPEC pricing policies. The results could assist in evaluating the degree to which the economic circumstance of the OPEC nations would be influenced by their pricing policies.

The world price of oil is assumed to be 50% higher than the value determined in the Reference Case for 1981 and all subsequent years.

ISSUE GROUPS

Each model was run for the various scenarios using standardized inputs. Outputs describing world oil supply, demand, and price, disaggregated by regions of the world, were produced and made available to all group members. Interpretation of results was the responsibility of four issue groups which examined model outputs and developed conclusions based upon their judgment as to the relevant questions, methodologies, and strength and limitations of the

various models. These conclusions were reviewed and refined by the working group as a whole.

The remainder of this Summary Report presents in greater depth working group conclusions. These are organized into four sections, corresponding to the four issue groups. The first, "The World Oil Market: 1980-2020", presents basic data on projections of oil supply, demand, imports, and price, developed by applying the various models to the scenarios. In addition, the impacts of policy choices and other uncertain events on world oil price and, to a lesser extent, on quantities are described. The second section, "Oil Supply Interruptions", focuses attention on potential oil market ramifications of future supply disruptions. In addition, the role of import reduction measures in moderating these impacts is discussed and quantified. The third section, "The Value of Reducing Oil Imports", draws heavily upon the results from the preceding two sections to quantify the economic benefits of reducing oil imports, benefits stemming from reduced oil price growth in normal years and reduced vulnerability to the periodic supply interruptions. The final issue-group section adopts a longer time perspective, addressing questions of "The Transition to New Energy Sources". The price patterns prior to large scale adoption of non-conventional energy sources and the impacts on price patterns of alternative adoption rates provides the central theme of this section.

THE WORLD OIL MARKET: 1980-2020

Central to energy policy deliberations, to technology development decisions, to corporate strategic planning, and to operating decisions in virtually all sectors of national economies are questions of the future price and availability of oil. The world oil situation shapes natural gas pricing in domestic and international markets, limits the profitability of coal mining, transportation, and conversion processes, makes investments in solar energy, biomass, or other technologies profitable or unprofitable, determines the extent of economically viable energy conservation, and shapes the relative desirability of alternative electric generation technologies. In addition, changing oil prices and availability profoundly shape the airline, railroad, and automobile industries, and all other elements of the transportation system, and, through fertilizer costs and biomass energy utilization, may alter the global food situation. And changing oil price and availability may continue to radically alter the international distribution of economic and political power.

Because projections are so dependent upon the accuracy and completeness of assumptions, we did not seek to construct any one scenario as the most likely course of events. Rather, we sought to capture a broad range of plausible future states of the world. Thus, we believe that the model projections indicate likely bounds on future movements in oil price and quantities.

This section provides a detailed look at the price and availability conclusions stated previously. The basic focus will be on a non-disrupted world oil market. More intensive examination of oil markets during disruptions will appear in a subsequent section. We begin with an overview of projections and follow with a discussion of those factors influencing world oil markets.

MARKET TRENDS

World Oil Prices

The unmistakable long-run projected trend of world oil prices¹³, adjusted for inflation, is upward. It can be expected that, following a several year slack oil market, oil prices will again begin rising, perhaps sharply, before the end of this decade.

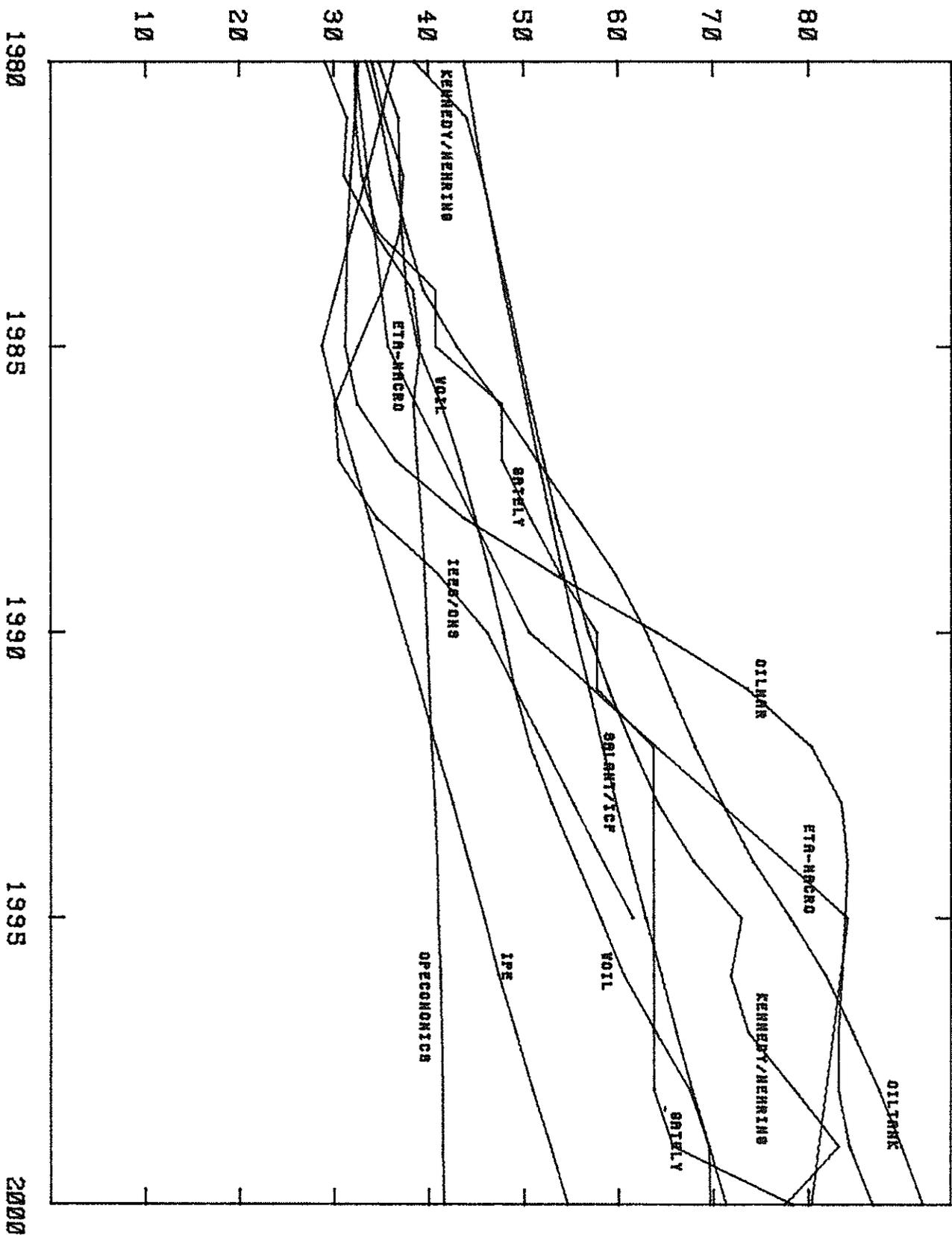
Although the general trend of prices is upward, the pattern of price changes can be expected to vary over our time horizon. Through the early and middle 1980's, the world oil market may remain fairly slack with nominal prices increasing less rapidly than the general inflation rate or decreasing if no disruptions occur. This trend is already readily apparent. By July, 1981 (at the time of this writing) average world oil prices, in constant dollars, were more than \$2 per barrel below their early 1981 peak level. Spot market prices had dropped more dramatically, signalling future declines in price of oil sold under long-term contracts and future declines in average price. This slack oil market could last through the middle of the decade.

However, beginning in the late 1980's and continuing into the first decade of the twenty-first century, oil prices are projected to increase, possibly quite rapidly. This long-run upward trend can be expected to occur primarily because the growth in oil supplies is projected to be slower than the growth in oil demand brought on by world economic expansion.

Within the first two decades of the next century, lower assumed economic growth rates coupled with increases in the supply of non-conventional oil, can be expected to dampen the rate of increase in oil prices, possibly halting or reversing the upward trend.

Figure 1 illustrates the Reference Case oil price projections through the year 2000 for the various models,¹⁴ with all prices (in this and other

CRUDE OIL PRICE (1981 DOLLARS)



REFERENCE CASE PRICES

Figure 1

graphs) expressed in constant 1981 dollars.¹⁵ The overall trends are evident even with the variation among the models.

With the exception of Kennedy/Nehring and Salant/ICF, both intertemporal optimizing models, Reference Case prices are projected to be relatively flat at least through 1984, and perhaps longer.¹⁶ For example, projected prices reach their lowest levels in 1985 for OILMAR and IPE and in 1986 for IEES/OMS. Other models generally show slight upward trends throughout the period.

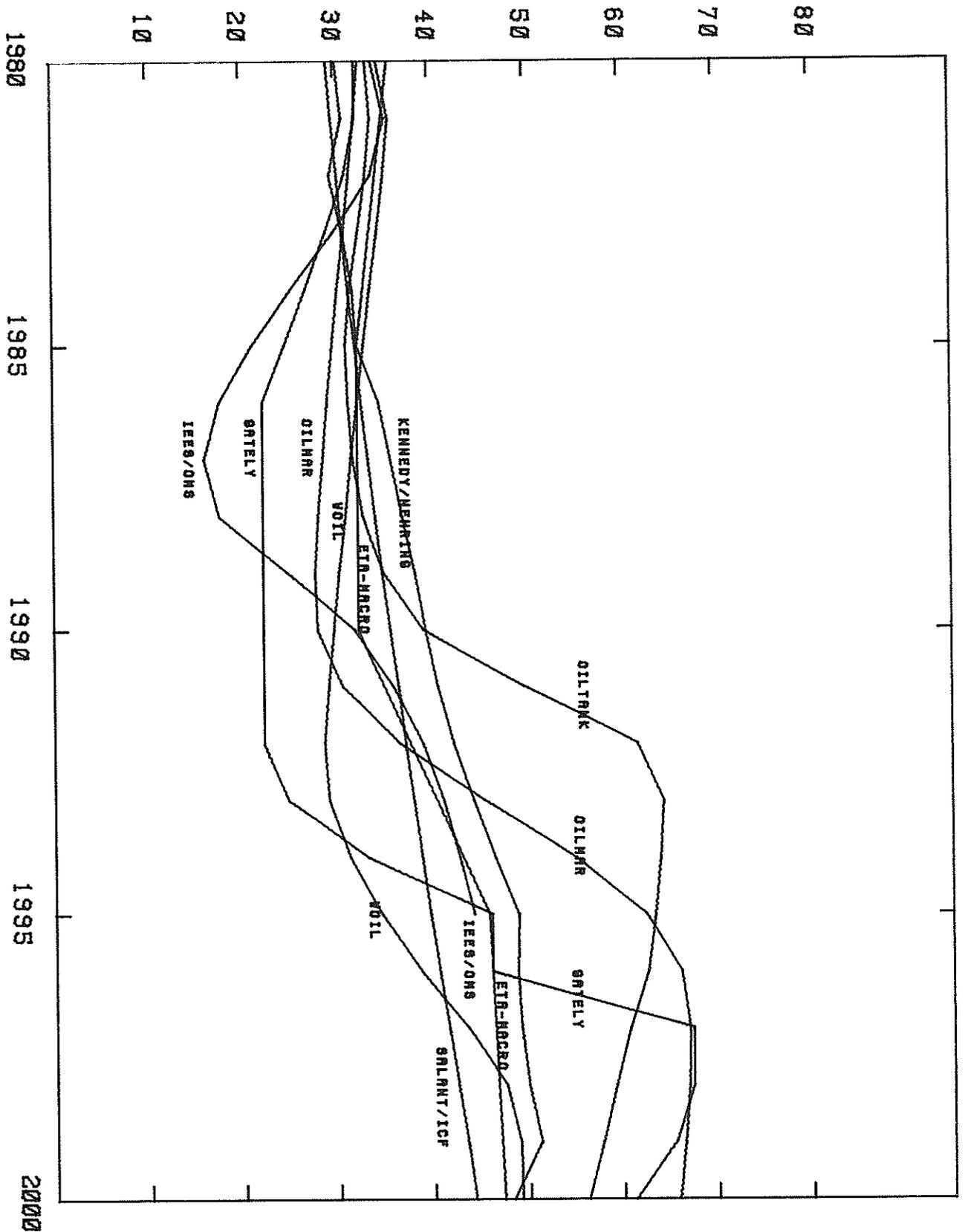
By the end of the decade, however, the upward trend in prices appears. In 1990, oil price projections in the Reference case range from a low of \$38 per barrel (1981 dollars) for the IPE model to a high of over \$60 for OILTANK with a median of over \$50. By the year 2000 the range is from \$42 to \$90 per barrel, with a median of \$70.

These changes can be expressed also in terms of the rates of growth of real prices. In the Reference Case, the median real price increases by 2% annually between 1980 and 1985, by 6% annually for the next five years, and by 4% annually over the last ten years of the century.

Although the trend of prices is projected by all of the models to be upward, the patterns of price variations and the overall rates of change are quite uncertain. As is apparent in Figure 1, even after we have standardized the assumed OPEC production capacity, the economic growth rates, the demand elasticities, and many other key factors, the variations in projected prices are large. As we vary these key factors in the alternate scenarios, the range of possible future prices grows even larger.

The Optimistic Scenario incorporates the most favorable conditions for oil consumers considered realistically imaginable by the working group. The results, shown in Figure 2, again indicate the price of oil increasing, possibly doubling over the next forty years. But the early-year declines are more apparent. Even in this scenario, by 1995 all models suggest prices

CRUDE OIL PRICE (1981 DOLLARS)



OPTIMISM CASE PRICES

Figure 2

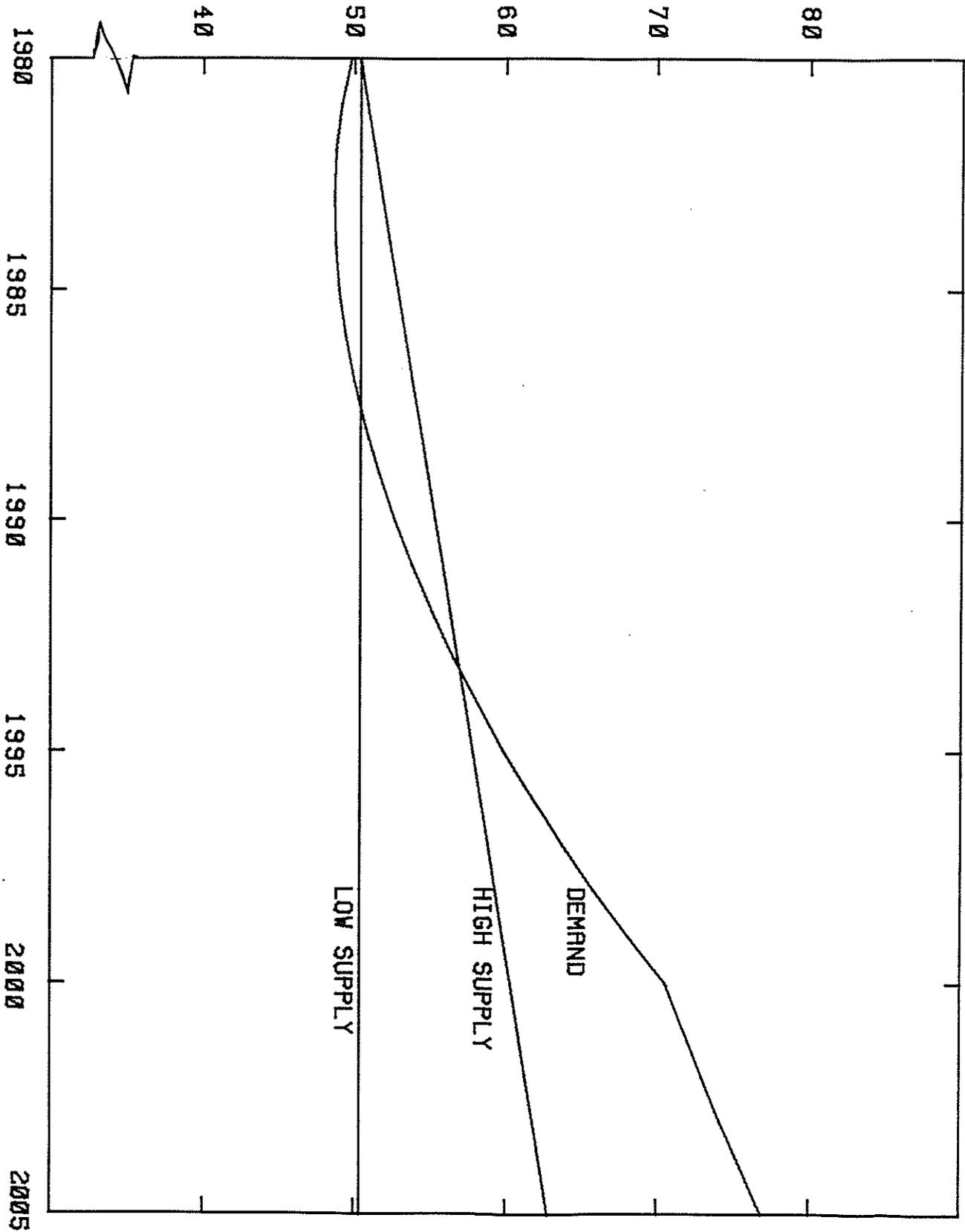
higher than current levels and most project further increases before the turn of the century. Thus, even the Optimism scenario suggests oil prices at or above \$45 per barrel by the year 2000, a figure roughly 40% higher than current levels.

The economic forces behind these price patterns can be illustrated by means of a simple transparent analysis of oil demand trends, an analysis designed to illustrate why these broad price trends emerge from the model projections. In Figure 3 we have provided a projection of oil demand under the assumption that real world oil prices were to remain constant at their 1980 levels. In addition we have plotted two possible oil supply trends. A comparison of anticipated supplies with the constant-price demands can indicate pressures to increase or to decrease prices from those prevailing in 1980: greater supply implies prices will tend to decline while greater demand implies that real prices can be expected to exceed their 1980 levels.

The projected demands are calibrated to 1980 actual levels, increase with economic growth, and decrease gradually in response to the pre-1981 oil price rises. Price elasticities, adjustment rates, and economic growth rates have been chosen to be consistent with the study design.¹⁷ The low supply projection is based upon an assumption that total oil supply to WOCA remains constant over time, while the high projection is based upon an assumption that the total supply increases by 0.5 MMBD each year after 1980.

Under the assumption that real oil prices remain at their 1980 levels, Figure 3 shows world oil demand decreasing to 1983 and subsequently increasing. This pattern results from two factors which work in opposite directions. The price increases which occurred between 1972 and 1980, when taken alone, would result in a pattern of declining demand, with the greatest declines coming in early years. The growth of the world economy, when taken alone, would result in growing oil demand, with the greatest growth occurring

SUPPLY AND DEMAND (MMB/D)



CONSTANT PRICE PATH OIL DEMAND VS SUPPLY
FIGURE 3

in the later years. The former effect dominates in the first few years while the latter effect dominates subsequently. The net result (under an assumption that real prices remain at 1980 levels) is the illustrated pattern of early year demand declines and subsequent year demand growth.

Figure 3 helps to explain the broad price conclusions derived using the models. If there are no oil supply interruptions, under the lower supply projection, Figure 3 suggests that market clearing prices would decline below the 1980 levels for several years. The movement of actual prices, however, is more uncertain since OPEC price administration inhibits price declines during periods of slack oil markets. But by 1987 for the lower supply projections and by 1993 for the higher projection, market clearing and actual prices must rise above 1980 levels. The simple analysis thus helps explain the model projections which suggest that a period of oil market slackness will be followed by an era of rising real oil prices.

Several factors could lead to prices differing from the Reference Case levels. Supply disruptions, lower demand elasticities, lower supplies of energy from non-OPEC nations, lower OPEC production capacity, or faster economic growth could further increase prices, while higher oil demand elasticities, greater production of oil substitutes, expansions in OPEC production capacity, discoveries of large reserves of conventional oil, less costly non-conventional energy sources, or slower oil demand growth in the less developed countries (LDC's) could result in lower price.

The influence of several of these factors is apparent already. Since the scenarios were defined (January 1980), world economic growth has been more sluggish than anticipated and hence world oil demand has been lower than projected. Decontrol of U.S. oil prices has further reduced oil demand in the United States. Reductions in the magnitudes of non-governmentally held stockpiles of oil has further slackened oil demand; the study design assumed

stocks would be increased, not decreased. The result has been a softer world oil market and lower world oil prices than suggested by the Reference Case projections. On the other hand, OPEC nations have reduced their oil production rates more than was anticipated at the beginning of the study and thus oil prices have remained more stable than would have been expected with the oil demand reductions seen to date.

These net result of the unforeseen changes may be prices lower during the next few years than suggested by our Reference Case results. Hence our conclusion that real prices may continue declining over the next few years unless there is another oil supply disruption. These factors, however, cannot be expected to greatly influence our longer term price projections. U.S. oil price decontrol is a one-time occurrence. Recovery of the world economy can be expected to bring economic activity more in line with our earlier projections. The drawdown of oil stockpiles, motivated by an expectation of falling prices, cannot continue indefinitely. Furthermore, once firms again expect price rises or tight oil supplies, they will again build up their oil inventories. Thus the longer-term price increases can still be expected.

The increased oil prices experienced since 1973 will continue to provide a major motivating force for increasing oil consumption and expanding non-conventional oil supplies and oil substitutes. Increased oil prices will motivate substitution of natural gas, coal, solar, biomass, and nuclear energy as well as energy conservation in all economic sectors. These price increases may also stimulate further governmental responses aimed at increasing energy supply, facilitating interfuel substitution, and encouraging energy conservation. These quantity projections will be discussed in what follows.

Oil Quantities

We expect the world's conventional oil production to increase slowly until the end of the century, by which time the production of conventional oil is likely to begin declining. While our assumption of constant OPEC production capacity implies that OPEC oil production will not exceed its historical peak rates, declining OECD production may be offset by new supplies from the LDC's. Rapid discovery and development of petroleum resources in these countries could more than offset the depletion of OECD reserves, allowing total world oil production to increase slowly over the next two decades.

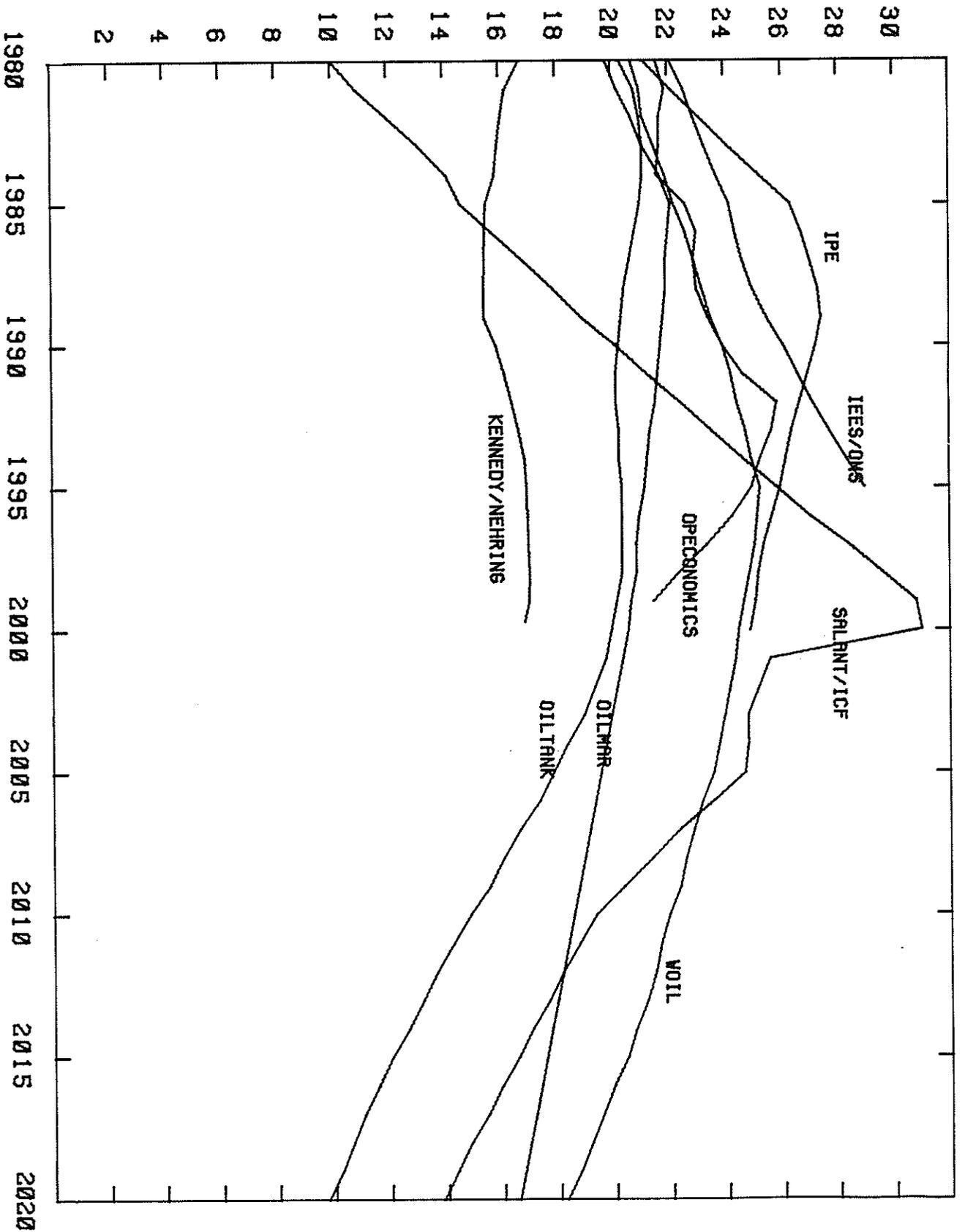
The quantity estimates projected using the various models in the Reference Case are displayed in Appendix A for four years, 1980,1990,2000, and 2020.

Figure 4 illustrates the projections of Reference Case conventional crude oil production from the non-OPEC countries¹⁸ (OECD plus the LDC's). Although wide variations exist among the projections, with the exception of Salant/ICF¹⁹, none project non-OPEC crude oil production to reach 30 MMBD. Four project slowly increasing production levels over the next decade. And all project a post-2000 pattern of declining crude oil production.

Significant growth in crude oil production cannot be expected within the OECD nations. In the Reference Case, no models except Salant/ICF project OECD crude oil production to increase by more than 2.5 MMBD above the current level. And most project roughly constant or declining production.²⁰

In contrast to the oil production prospects for the OECD nations, the LDC's may experience increasing oil production. Mexican oil production will almost certainly increase. Continued exploration and development in other LDC's can be expected to lead to growing production rates.

CRUDE OIL PRODUCTION (MMB/D)



NON-OPEC OIL PRODUCTION

Figure 4

Of the five models which explicitly project LDC oil production, three (IEES/OMS, Salant/ICF, and IPE) show Reference Case production more than doubling from its 6 MMBD level by the end of the Century. OILTANK and Opeconomics show more modest growth in LDC production. However, despite the compatibility of the model results with our expectations, projections of LDC behavior based upon the current generation of models cannot be relied upon because many potentially important economic, political, and geological factors are not well understood.

Some of the differences among the model results can be explained. The relatively high production rates for IEES/OMS and for IPE seem to result from the assumption in these models of greater initially undiscovered resources. Moreover, IPE includes an exogenous base projection in addition to a price elasticity for oil production from Western Europe. OILMAR and Opeconomics specify all non-OPEC production exogenously. The Salant/ICF patterns stem from a variety of assumptions, including the instant adjustment of demand to price, perfect price foresight, maximization of discounted profits over time, and the supply constraints imposed upon the various actors. The low production rates in the Kennedy/Nehring model are not well understood. However, the low production rates in the Kennedy/Nehring model and the Salant/ICF model are consistent with the relatively high prices projected using these models (see Figure 1, presented previously).

A second growing component of overall petroleum supply is oil from unconventional sources such as oil shale, coal liquefaction, tar sands, and so on. The projections of unconventional oil production generally follow the study assumptions of 5 MMBD by 2000, increasing to 15 MMBD in 2010 and 30 MMBD in 2020. These projections are more nearly inputs to the models than outputs from the models.

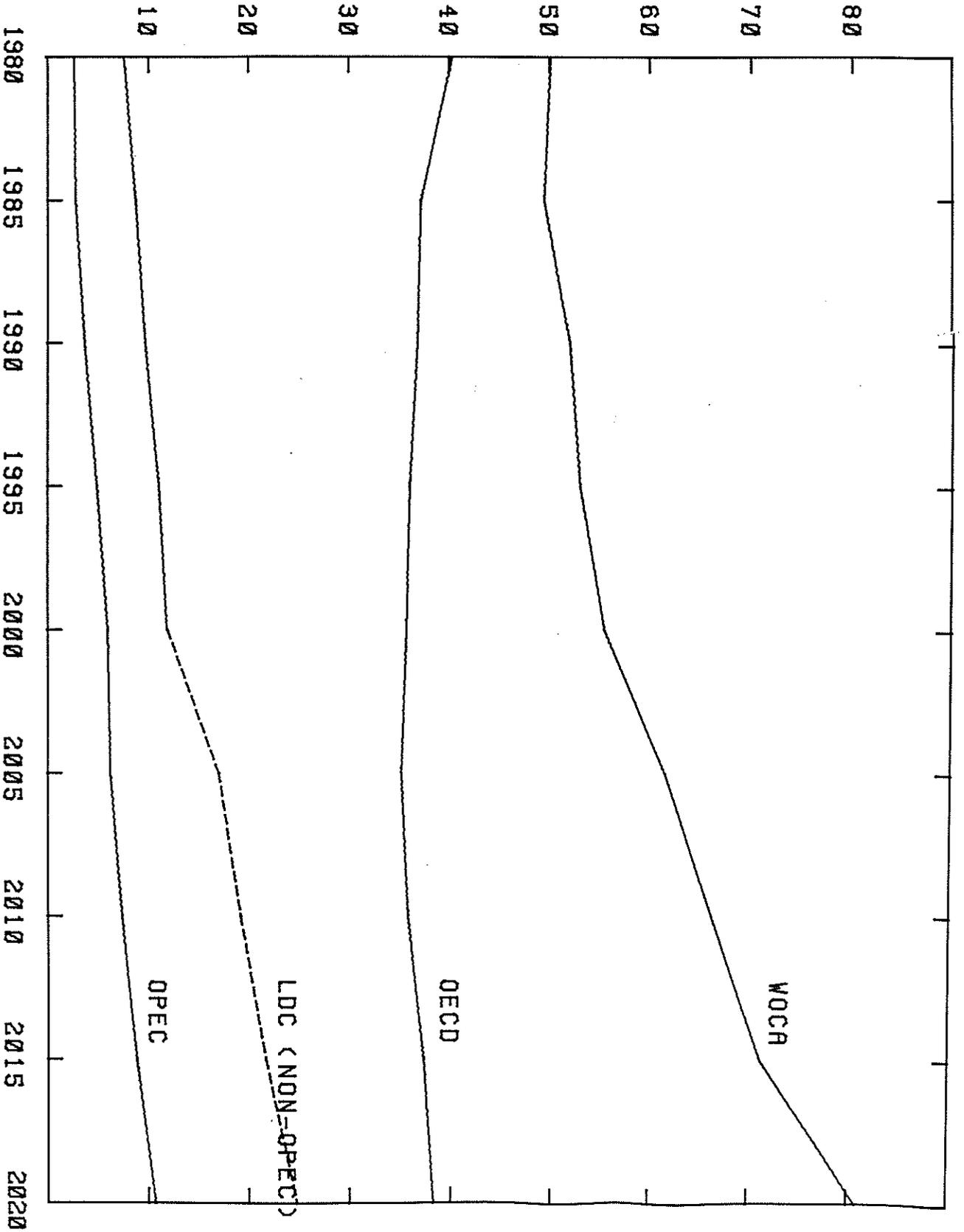
Consistent with the supply projections are the demand projections

generated using the models. Oil (deriving from both unconventional and conventional sources) will remain a major part of our energy consumption for many decades to come. In particular, the rapidly growing economies of OPEC and the oil deficient developing countries may consume increasing quantities of oil. Such an oil consumption growth, coupled with stagnant or declining conventional crude oil production, would mean declines in OECD oil consumption.

These patterns are illustrated by Figure 5 which displays median Reference case oil consumption projections for three groups of nations (OECD, OPEC, non-OPEC LDC's) and for the WOCA total.²¹ In Figure 5, solid lines have been used whenever outputs were available for four or more models; a broken line has been used when fewer than four were available. While Figure 5 illustrates the basic trends, it tends to exaggerate the growth rates between 2000 and 2005. This occurs because some models project consumption rates only up to the year 2000 and because those models which project beyond 2000 happen to be the same ones that produce relatively high estimates of consumption. The net result is an over-estimate of LDC and WOCA consumption growth rates between 2000 and 2005.²²

Despite the decline in OECD oil use, we can expect a continued dependence of OECD countries upon oil imports. However, as a fraction of all oil consumption or of all energy consumption by the OECD countries, OPEC exports can be expected to decline significantly. Thus, while the economic problems of vulnerability to oil supply disruptions may decline by the turn of the century, the problems of costly oil imports and market uncertainty will persist.

OIL CONSUMPTION (MMB/D)



MEDIAN CONSUMPTION RATES

FACTORS INFLUENCING WORLD OIL MARKETS

The key factors which can be expected to predominantly influence oil price and availability include OPEC choices of production capacity and capacity utilization, non-OPEC supply of conventional and unconventional fuels, and oil demand, particularly in the developing countries. Oil demand in turn is influenced strongly by economic growth rates, by opportunities to substitute other energy forms or other productive inputs (such as labor, capital, or technology) for oil, and by public policy choices.

The sensitivity of world oil price and availability to changes in key market factors can be analyzed by conceptually dividing the world oil market into an OPEC sector which is a net exporter of oil and a non-OPEC sector which is a net importer. Certain market factors will have a direct influence upon OPEC export supply while others will have a direct influence on non-OPEC import demand.

This way of looking at the world oil market emphasizes the theoretical point that any two market factors which influence non-OPEC import demand by equivalent amounts will have equivalent impacts on oil prices. In addition, if an OPEC supply curve can be defined, shifts of equivalent magnitude in the OPEC supply curve and in the non-OPEC import demand curve will also have equivalent price impacts. Figure 6 illustrates the analysis. The solid lines represent the Reference Case non-OPEC oil import demand and the Reference Case OPEC oil export supply. A 2 MMBD outward shift in the OPEC supply curve (broken line) leads to the same price impact as the 2 MMBD inward shift in the non-OPEC import demand curve (broken line). However, the former shift will reduce quantities exchanged while the latter will increase quantities. The inward shift in the non-OPEC import demand could be caused by a 2 MMBD increase in non-OPEC domestic oil supply or an energy conservation program which led to a 2 MMBD reduction in non-OPEC oil demand. Both would have the

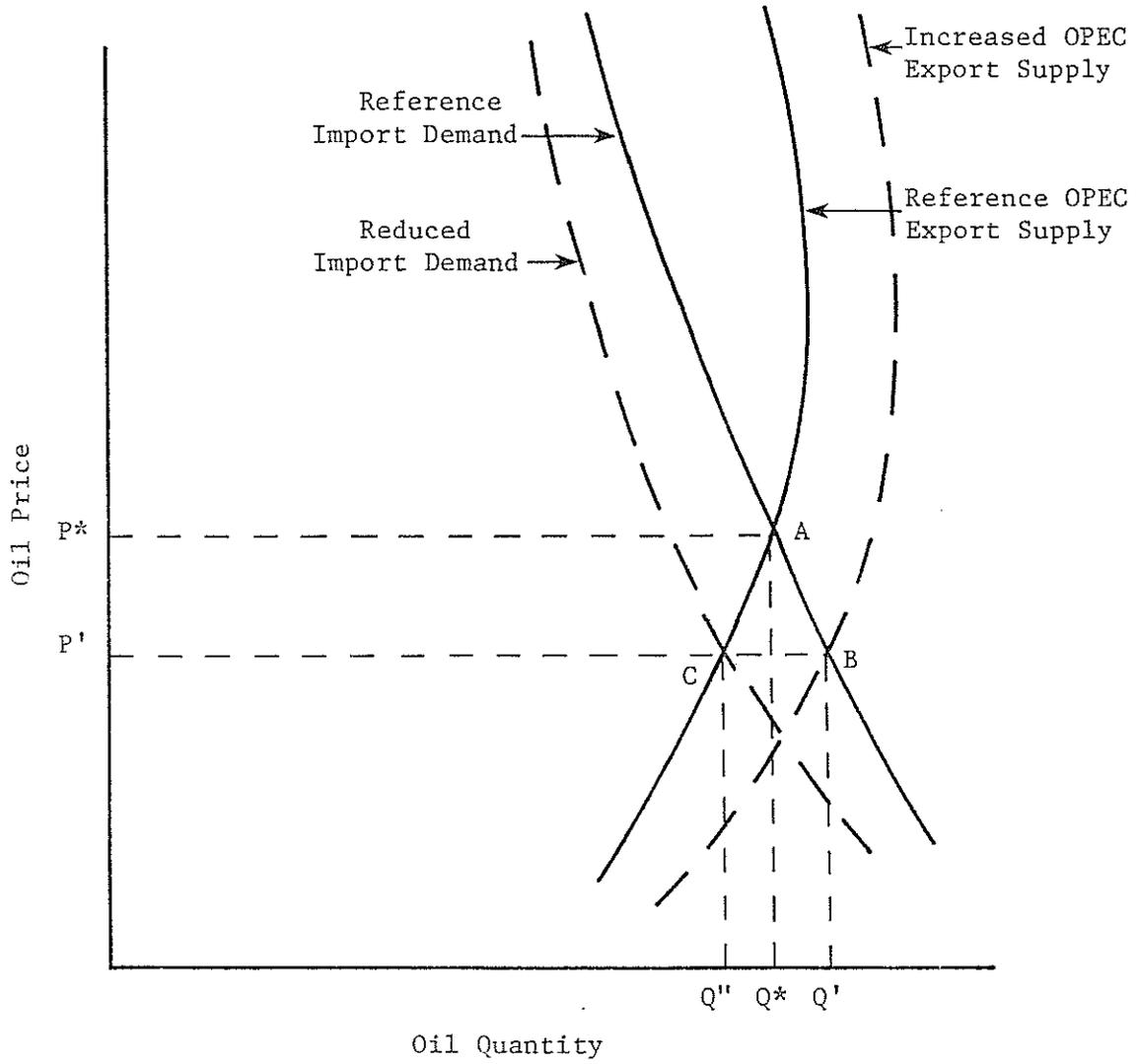


Figure 6 Price and Quantity Impacts of Increased OPEC Export Supply or Reduced Import Demand

same impact on world oil prices and net imports from OPEC.

The magnitude of the price change depends upon the degree to which demand and supply are responsive to price. If oil demand and supply elasticities are low and consequently the import demand elasticity is low, a demand reduction may greatly reduce prices. Conversely, if elasticities are high, that same demand reduction will lead to only small price declines.

The simple static supply/demand framework must be expanded somewhat in order to describe the more complex dynamic adjustments in the world oil market and those in the real models. Demand and supply in each year may depend upon prices in previous years and upon expectations of future price changes. With OPEC dominating world oil supply, prices may quickly adjust upward toward market clearing levels but downward only slowly. Therefore, if a policy leads to declining prices, the actual price change over several years may be larger than, not smaller than, the price change during the first year. For upward trending prices this phenomenon may also occur, although not as noticeably. In addition, the equivalence of impacts between supply and demand shifts will be valid only if these shifts have equal magnitudes at every moment of time. These dynamic aspects of the markets cannot be addressed simply without use of the complex models.

In what follows we will examine the potential price impacts of changing the key market factors which influence OPEC export supply and non-OPEC import demand. As already noted, the price impacts of a change in net import demand should be roughly equivalent on a dollar-per-barrel basis, regardless of the specific phenomenon responsible for the change. Therefore we will often refer to the price impacts per 1 MMB/D import demand reduction, in order to test the consistency of the model results with our theoretical understanding. In addition, we can apply model results derived from one class of shifts to analysis of other factors which lead to equivalent shifts in import demand.

Oil Demand Reduction

Deliberate policies instituted by the oil importing nations to reduce oil demand (or to increase domestic supply) will have direct impacts on oil import demand and consequently on price. In our Oil Demand Reduction Scenario we have postulated a reduction in energy demand which varies over time but which is independent of oil prices. This scenario variation therefore reduces oil import demand by precisely the same amount as oil demand is reduced.

Table 4 displays results of this exogenous decline in oil demand. The top line displays the policy-induced demand reductions (measured in MMBD), from the Reference Case levels, for four different years. The first group of lines shows, for each of these models, the projected price reductions stemming from these demand reductions. The final group of lines shows the projected price changes per 1 MMBD oil demand reduction.

Over the first five years, as oil prices slowly adjust in the slack oil market, prices are reduced \$0.10 to \$2.10 for each 1 MMBD demand reduction, with a median of \$1.00. The projected amount depends upon the price adjustment speeds incorporated into the models.

The 1990 results represent medium term impacts after most price adjustments have been felt. They range between \$0.80 and \$3.20 price reduction for every 1 MMBD demand reduction, with a median of about \$1.20. The central eight of ten estimates range between \$0.90 and \$2.40 per barrel price decrease for every 1 MMBD oil import demand reduction. It is this range that we will use in describing the medium term price impacts of oil import reductions.

After 1990, price reductions per 1 MMBD import demand reduction shrink slowly, in 2010 ranging between \$0.00 and \$2.30, with a median of \$0.50.

The price responses to the demand reduction grow until they reach a peak a number of years after the postulated demand reduction program is initiated,

Table 4

**PRICE REDUCTIONS DUE
TO OIL DEMAND REDUCTIONS**

	1985	1990	2000	2010
Demand Reduction (MMBD)	5.0	6.67	10.0	15.0
Price Reduction (\$/bbl)				
Gately*	\$10.10	\$15.60	\$ 8.90	\$ 2.30
IEES/OMS	7.80	7.60		
IPE	0.60	8.70	16.30	
Salant/ICF	5.40	6.20	8.80	14.40
ETA-MACRO	3.50	13.40	16.00	7.90
WOIL	5.20	16.30	15.30	6.20
Kennedy/Nehring	6.30	6.90	6.00	0.00
OILTANK*	8.50	6.10	17.70	23.80
Opeconomics*	1.60	5.40	4.90	
OILMAR*	2.60	21.70	20.30	33.90
Price Reductions per MMBD Demand Reduction				
Gately*	\$2.10	\$2.40	\$0.80	\$0.20
IEES/OMS	1.60	1.10		
IPE	0.10	1.30	1.60	
Salant/ICF	1.10	0.90	0.90	1.00
ETA-MACRO	0.70	2.00	1.60	0.50
WOIL	1.00	2.40	1.50	0.40
Kennedy/Nehring	1.30	1.00	0.60	0.00
OILTANK*	1.80	1.00	1.70	1.60
Opeconomics*	0.30	0.80	0.50	
OILMAR*	0.50	3.20	2.00	2.30

* For Gately, OILTANK, Opeconomics, and OILMAR, the numbers displayed are five year averages of model results. This averaging was needed because of the oscillatory nature of the results from these models.

after which time the responses shrink. This time pattern results from a combination of two adjustment lags: the gradual adjustment of OPEC administered price to changing demand for OPEC exports and the even slower adjustment of that demand to price changes. As demand changes relative to supply, prices do not adjust instantly to the new market clearing levels. Rather in the OPEC-administered market, prices adjust slowly, sometimes over a period of years, toward these levels. Thus in a slack oil market, we may observe relatively little price change during the first few years after a modest demand shift, although that change may grow over time.

Likewise, the demand adjusts only slowly in response to changing energy price because the capital stock of energy using equipment is replaced only gradually: i.e., demand and non-OPEC supply elasticities increase over time. Therefore the impacts on market clearing prices of a given import demand reduction tend to shrink as the years go by. This latter phenomenon alone would imply that price reductions per unit demand reduction should decrease as time goes on. The combination of the two adjustment processes implies that the largest price change per MMBD of demand shift occurs neither right away nor after many years, but in the mid-run, after the slow price adjustments have already occurred but before most of the demand adjustments in response to those price changes have been felt.

After 2005, some models show no price impact whatsoever. In these models, unconventional oil is available in sufficient quantities to limit world oil price to the cost of oil from unconventional sources. For these models, therefore, no price reduction is felt; the only impact of the oil demand reduction program is a decrease in the growth of the unconventional fuels industry.

Economic Growth

World economic growth patterns comprise another factor -- a particularly crucial and difficult to predict factor -- that may influence world oil price through its impact on oil demand. Our models required as inputs assumptions about future economic growth rates. We therefore standardized the economic growth rates expected to occur if world oil prices were to remain constant at their 1980 levels. Those models which included a feedback from higher energy price to economic growth projected adjustments downward in the economic growth rates in response to higher price. These constant-oil-price growth rates are displayed in Table A.3 (Appendix A). Up to the turn of the century, OECD GNP growth rates are assumed to average slightly over 3 percent per year, OPEC rates 6.4 percent, and the LDC's 5.1 percent in the Reference case. Post-2000 rates in all cases are assumed to be significantly smaller.

The impact on world oil markets of alternative future economic activity levels can be quantified by comparing oil prices in the Reduced Economic Growth scenario to those in the Reference case. Table 5 displays, for three years, the median percentage reduction in WOCA GNP from the Reference case levels and the resultant minimum, median, and maximum reductions in price and in consumption. These latter changes are expressed as percentage price (or quantity) change per 10% GNP change.

In most of the models, oil demand would be roughly proportional to GNP if prices were to remain unchanged. Thus, each 10 percent GNP decrease could be expected to depress consumption by 10 percent if there were no changes in prices. However, because prices were not held constant between the scenarios, in 1990 each 10 reduction in GNP yields a median consumption decrease of only 2 percent. The 8 percent difference is accounted for by the large price decrease (24 percent price decrease per 10 percent GNP decline.) This pattern

Table 5

**PRICE AND QUANTITY IMPACTS OF
REDUCING ECONOMIC GROWTH RATES**

	1990	2000	2020
Median % Reduction in GNP (Low Economic Growth vs Reference)	10.2	19.3	30.6
Price Reduction per 10% GNP Reduction			
Maximum	40%	17%	15%
Median	24%	10%	5%
Minimum	12%	6%	-13%
Consumption Change per 10% GNP Reduction			
Maximum	- 1%	- 5%	2%
Median	2%	4%	8%
Minimum	7%	10%	15%

is especially true in early years: actual declines in consumption are far smaller than the GNP declines.

The converse is true for price projections. During the first twenty years, the resulting percentage price reductions are greater than the percentage GNP reductions while in later years price variations are smaller than the GNP variations. This time pattern occurs because, in response to a given percentage price increase, supply and demand quantities adjust more in the long-run than they do in a shorter time period. For this reason, smaller price changes are required in the long-run to motivate a given change in quantity than are required in a short time period.

These results suggest that accurate estimation of future economic activity (or for that matter, energy conservation actions, availability of oil substitutes, or any factor influencing the oil demand functions) is essential for projecting medium-run and long-run world oil price but is far less important if projection of future world consumption is the goal.

In our other sensitivity tests we displayed oil price changes per MMBD of import demand change. Although it would have been desirable to present comparable data here, this objective cannot be met in a meaningful way. Decreases in GNP influence the demand for oil both directly and indirectly. The indirect effect occurs because decreases in GNP directly decrease demands for all other forms of energy. In turn these demand changes for electricity, natural gas, and coal result in price reductions and hence increase their relative desirability vis a vis oil. This then indirectly decreases the demand for oil.

While these decreases in the demand for any energy form will tend to decrease world oil demand and, hence, price, the impacts vary depending upon the fuel whose demand was altered. For example, if coal demand were decreased by the energy equivalent of 1 MMBD of oil, the world oil price would be

reduced by far less than would be the case with a 1 MMBD oil demand reduction. A decrease in natural gas demand would have an intermediate impact on oil price. (Equivalently, if demand were shifted from oil to coal or from gas to coal, the world oil price could be expected to decline even though the demand for energy as an aggregate remained unchanged.) Since we did not standardize these substitution possibilities, we cannot say precisely what percentage shift in the oil demand function corresponds to a 10 percent shift in GNP. Thus displaying price changes either per unit of oil demand reduction or per unit of energy demand reduction would not have been meaningful.

The above discussion does suggest some important differences in the models. A model which includes oil only cannot explicitly account for these substitution effects induced by changes in GNP. In these models a program which reduces the demand for oil by 1 MMBD but which leaves all other demands unchanged will have the same projected price impact as would a reduction in economic growth which reduces oil demand by 1 MMBD and at the same time reduces the demand for all other fuels proportionately.²³ At the other extreme, a model which treats all energy demands as a single aggregate with oil as the fuel of "last resort", overstates the substitution possibilities. Such a model would project the same price impact for a program which reduces oil demand alone by 1 MMBD as it would for an economic growth change which reduces the sum total of all energy demands by the energy equivalent of 1 MMBD. The former class of models tends to understate the sensitivity of oil prices to changing economic growth rates while the latter class tends to overstate the sensitivity.

The Demand Elasticity for Oil

Other factors influencing demand are also known only imprecisely. One such parameter is the price elasticity for oil or for energy. If two demand

functions are both based upon price and quantity observations from history, then for prices above their historical levels, the lower the demand elasticity, the higher the demand at a given price. Higher demands imply higher market clearing prices. Thus a lower demand elasticity implies a higher world oil price and a higher quantity consumed.

Table 6 shows the percentage price increase (from the Reference case) resulting from reducing the elasticity of demand to 5/8 of its Reference level. This change generally increases projected oil consumption, but by a relatively small percent. However, price changes may be great. Thus future price projections may be highly sensitive to alternative assumptions about the demand elasticity, but quantity projections may be relatively insensitive.

Contrary to what may be expected, the percentage price increases vary radically across the models: three models show 1990 price increases of less than 10% while two show increases of over 120%. While we cannot be sure why such surprising variations occur, the high degree of variation among these results is cause for concern as to whether procedures for calculating the sensitivity of prices to changing elasticities are standardized sufficiently to allow any degree of comparability.²⁴

Non-OPEC Oil Supply

Changes in the supply of conventional and unconventional oil can influence world oil prices and quantities, as was illustrated in Figure 6. Figure 7 illustrates how long-run changes in non-OPEC oil production translate into changes in the world price of oil. On the horizontal axis are plotted changes (from Reference case levels) in non-OPEC oil production for two scenarios -- Technological Breakthrough and Restricted Backstop. On the vertical axis are corresponding percentage price changes. The slope of a line from the origin

Table 6

**PRICE AND QUANTITY IMPACTS OF
REDUCING ASSUMED DEMAND ELASTICITY**

	1990	2000	2010
Reduction in Elasticity (Low Elasticity vs Reference)			
To 5/8 of Reference Level			
Price Increase (%)			
Gately**	81%	31%	26%
IEES/OMS	4%		
IPE	171%	146%	
Salant/ICF	39%	41%	54%
ETA-MACRO*	9%	73%	-14%
WOIL	19%	13%	6%
Kennedy/Nehring*	121%	131%	166%
OILTANK	26%	60%	61%
Opeconomics	3%	3%	
OILMAR	8%	103%	123%
WOCA Consumption Increase (%)			
Gately**	2%	9%	12%
IEES/OMS	2%		
IPE	16%	18%	
Salant/ICF	- 6%	1%	7%
ETA-MACRO*	6%	10%	36%
WOIL	0%	1%	3%
Kennedy/Nehring*	- 5%	0%	1%
OILTANK	7%	14%	37%
Opeconomics	1%	2%	
OILMAR	4%	- 2%	-2%

* Quantities are for OECD instead of WOCA.

** Consumption increase estimates are for all energy, not simply oil. Percentage oil consumption increases will be larger than percentage energy consumption increases, perhaps by a factor of 2-3.

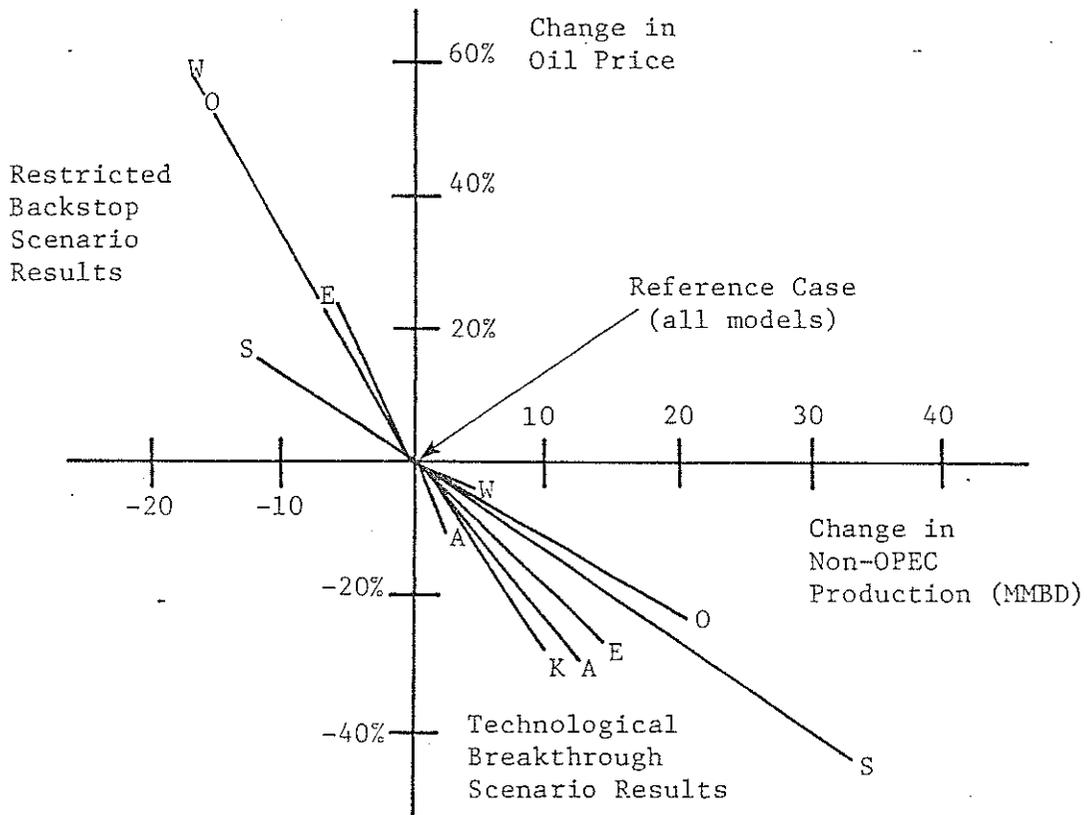


Figure 7 Change in World Oil Price with Change in Non-OPEC Oil Production: 2020 (changes from the Reference case)

to a given model result indicates the price change per MMBD increase in the quantity of non-OPEC (conventional plus unconventional) oil production.

For each model, on the average, a 1 MMBD increase in non-OPEC production from Reference Case levels reduces long-run oil price by 1% to 2%. In absolute terms, on the average, each 1 MMBD increase in production reduces world oil price by \$0.70 to \$2.70 per barrel. Price impacts for large decreases in production are greater: on the average, each 1 MMBD production decrease implies price increases between 1.7% and 4%, (\$1.60 and \$7.00 per barrel).

For production increases, the range of per-barrel impacts is similar to that for demand reduction measures, while for production decreases, these per-barrel estimates are larger. As discussed previously, measures to reduce demand should have the same per barrel impacts as measures to increase supply. However, the similarity of the measured ranges is somewhat deceptive since there are differences in concepts being measured. Figure 7 shows actual changes in production, not changes in the supply at a given price. Supply function changes would be somewhat larger. In order to be comparable in concept, we would need to use in our calculations changes in supply function. Such a procedure would reduce the per-barrel price impacts somewhat. But even with the conceptual differences, these data tend to confirm our earlier observation about the range of price impacts per MMBD reduction in oil import demand.

OPEC Capacity

By using the two disruption scenarios it is possible to estimate the effect on world oil conditions of a continued reduction in OPEC capacity. These effects could be illustrated by reference back to Figure 6. An increase in OPEC capacity would move the OPEC Export Supply curve to the right, leading

to market clearing at Point B. World oil prices would be decreased and the quantity of oil produced and consumed in the world would be increased by an amount less than the increase in OPEC capacity. The converse results occur in response to an OPEC capacity decrease.

The Disruption scenarios each postulate a 10 MMBD reduction in OPEC production capacity occurring suddenly in 1985. In the short-run, this capacity disruption leads to a sharp jump in oil prices. The magnitude of the projected change depends upon the model, but prices exceeding \$100 per barrel are generally reported. In addition, the recursive simulation models show prices oscillating for many years after the disruption. A more complete discussion of the short-run impacts of disruptions appears in the subsequent section of this Report, entitled "Oil Supply Interruptions". Our interest here is in the effects of these capacity reductions on long-run price trends.

The model projections of long-run price impacts per MMBD capacity reduction appear in Table 7 for two time periods, 2000 to 2010 and 2011 to 2020. Over this time horizon, production is reduced by 85% to 100% of the reduction in capacity. In the medium run (15-25 years) the reduction in OPEC capacity results in an average oil price increase ranging between \$0.80 and \$4.10. In the 25-35 year period, these price impacts are generally projected to be smaller. These results suggest a range of price impacts roughly consistent with our estimated impacts of import demand reduction measures.

Other Uncertainties

A major uncertainty concerns the ability of the oil importing developing countries to finance increased levels of oil consumption. If balance of payments problems or other financial considerations not represented in the models prevent the projected increases in LDC oil consumption from taking place, then our estimates of world oil prices will be biased upward and our

Table 7

LONG RUN PRICE IMPACTS OF
OPEC CAPACITY DECREASE

	2000-2010	2011-2020
Reduction in OPEC Capacity (Disruption vs Reference)	10 MMBD	
Price Change per 1 MMBD Capacity Reduction*		
Gately	\$0.80	\$0.80
Salant/ICF	1.70	2.20
ETA-MACRO	1.00	0.60
WOIL	3.30	0.20
Kennedy/Nehring	1.70	1.50
OILTANK	4.10	1.90
OILMAR	3.50	3.00

* Calculations were made for only those models that project prices for the years 2000 to 2020. The figures are the differences between the average post-disruption price during the two periods and the average Reference price, divided by the 10 MMBD capacity disruption. All are in 1981 dollars.

projections of OECD oil consumption will be biased downward. On the other hand, the growth in LDC revenues from their oil production along with the financial transfers from OPEC nations and the developed countries might preclude this possibility. These two alternative positions were strongly argued by working group members; no consensus was reached. However, most group members felt that estimates of prices associated with low economic growth may adequately incorporate this uncertainty.

Models of LDC oil demand are relatively few. Far less empirical research and modeling has been focused on this group of countries than on the developed world. Therefore, projections of LDC oil consumption and production -- including ours -- should be viewed with scepticism. This inherent uncertainty about future LDC conditions was reflected in our lack of consensus about the likely biases incorporated into the LDC consumption estimates.

A second important, yet uncertain, factor concerns the production policies of OPEC. The OPEC nations may have considerable latitude in determining production policies for the purpose of achieving non-economic goals. This latitude therefore makes any projections of oil prices and availability contingent upon political developments. This uncertainty was reflected by the many different representations of OPEC behavior incorporated into our models. In addition, other theories of OPEC behavior not included in any of our models were supported by working group members.

A third remaining question concerns the consumption and production patterns of the centrally planned economies (CPE's). Our scenarios assume that during the 1980's, net oil exports from the CPE's will decline to zero. Whether these countries may become net oil importers in the near future remains to be seen. But, the impact on world oil prices of such a change can be extrapolated from our model results. Every 1 MMBD oil import demand increase may increase mid-run world oil price by between \$0.90 and \$2.40 per

barrel (probably less than \$2). Thus our results suggest that while the political implications of such a change could be great, the direct impacts on the world oil market of, say, 2 MMBD of net imports, would be relatively small.

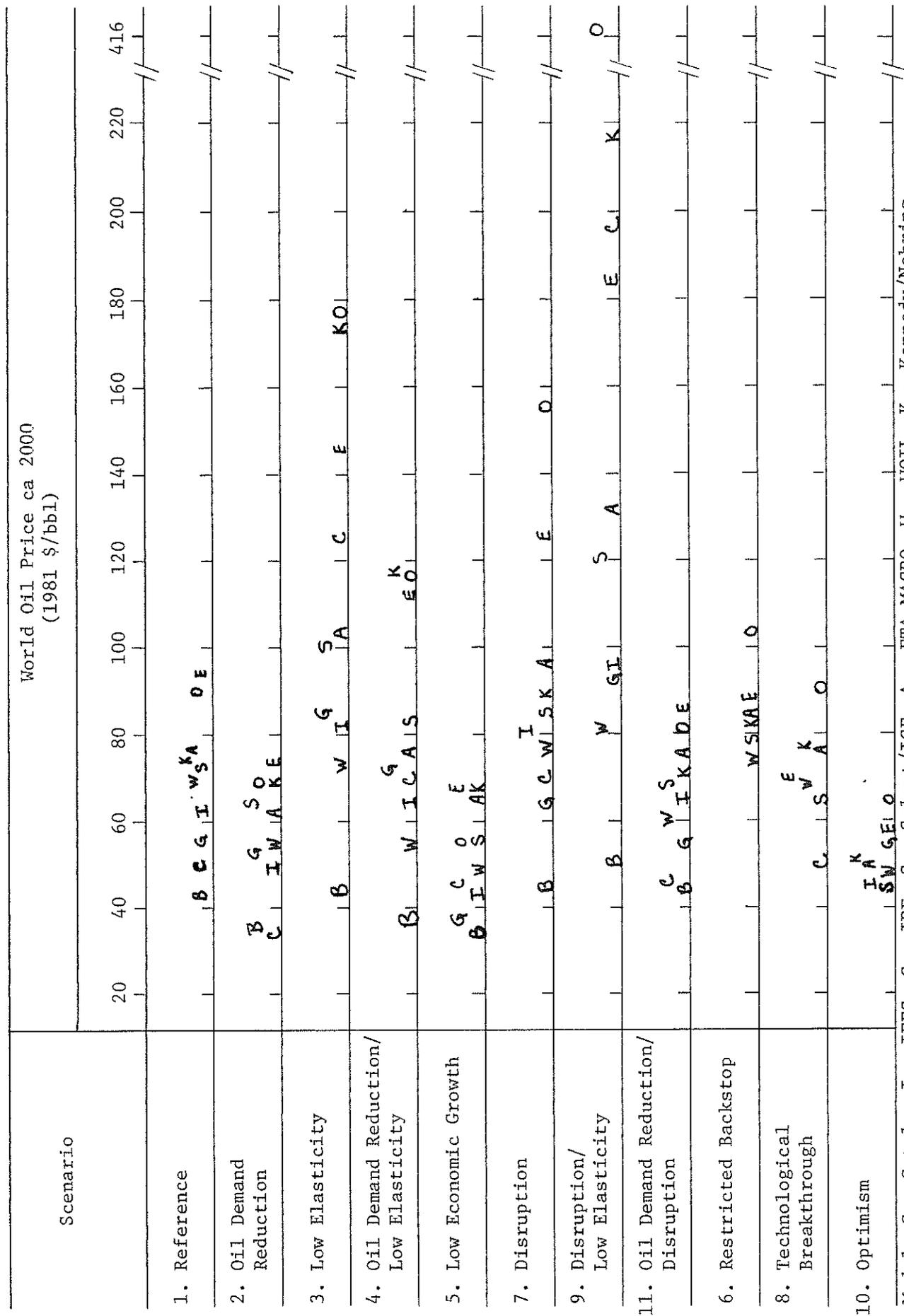
Several other uncertainties, including the policy environment and the possibility of sudden disruptions in oil supply have been addressed and are discussed in a subsequent section. We did not explicitly address other uncertainties: e.g., the growth of nuclear power, international natural gas trade, or coal use.

Summary

The range of prices projected using the various models for the ten scenarios is summarized in Figure 8, which shows projected world oil price in or around the year 2000, for the various models and scenarios. This figure clearly illustrates the difficulty of forecasting world oil prices. For any one scenario, differing beliefs about the world, as incorporated into differing models, result in different forecasts of future prices. For any one model, reasonable variations in the assumed state-of-the-world (technology, OPEC capacity, economic growth, demand elasticity, demand growth) lead to additional variations in the projections.

This figure highlights a central conclusion. While oil prices a decade or two in the future are highly uncertain, we should expect prices to exceed the current high levels. In only a very few combinations of models and scenarios are year 2000 prices projected to be as low as current levels. But whether price increases will be modest or dramatic is not clear. Furthermore, while gradual, steady increases are possible, so too are the dramatic escalations brought on by supply interruptions.

Figure 8 Scenarios and Price Results



Models G - Gately, I - IEES, C - IPE, S - Salant/ICF, A - ETA-MACRO, W - WOIL, K - Kennedy/Nehring,

E - OILTANK, B - Opeconomics, O - OILMAR

Note: For all models other than IEES/OMS and IPE, the average of prices between 1995 and 2005 is given.

For IEES/OMS, the 1995 price is presented while for IPE, averages between 1995 and 2000 are presented.

Analysis of various uncertainties allows estimation of the impact on oil prices of changing supply and demand conditions. Over a time horizon of several years, each 1 MMBD oil demand decrease or supply increase might reduce oil price by anywhere between \$0.10 and \$2.10 per barrel; in the longer run (10-20 years), the price range is tighter -- by \$0.90 to \$2.40 per barrel for every MMBD demand decrease or supply increase.

These price increases will motivate partially offsetting demand or supply changes, so that consumption or production variations will be smaller than the initiating changes in demand or supply. Therefore price changes per 1 MMBD of oil consumption decrease or oil production increase will be significantly higher than the above estimates.

The era of oil consumption is not at an end, but we expect slower growth in consumption over the next forty years. Conventional oil production is expected to decline. Increasing consumption in the face of declining production depends upon our projection of increasing availability of non-conventional sources of oil substitutes. Similarly, we expect the OECD nations to continue to be highly dependent upon the OPEC nations for oil. Some consequences of this dependence will be addressed in the following section.

OIL SUPPLY INTERRUPTIONS

The vulnerability of the oil importing countries to disruptions in supplies of crude oil became front page news during the 1970's. Whether the result of politically motivated embargoes, internal revolutions, or political/military conflicts, these disruptions have been -- and will likely continue to be -- very costly. And it is conceivable that control of Persian Gulf oil could pass to nations whose interests are in direct conflict with those of the Western world. Should that occur, disruptions or threatened disruptions could be used to gain economic and political advantage in ways not experienced heretofore.

The global interdependency of oil markets makes the effects of oil supply interruptions nearly inescapable. Even those who buy oil only from secure sources may find their supplies suddenly vanishing during a disruption as those who are cut off bid higher and higher prices for the remaining supplies.

Assessment of our vulnerability and of policies designed to reduce vulnerability requires evaluation of the consequences of many possible situations. In the present study, the effects of a sudden cutback in supply are examined by considering a permanent, but unanticipated, reduction in OPEC capacity of 10 MMBD initiated in 1985 while the world oil market is projected to still be "soft".

UNDERSTANDING INTERRUPTIONS

The Iranian crisis of 1979 provides a good example of effects on oil supply and price of a sudden reduction in oil production capacity. Prior to the 1978, Iran had produced more than 5.5 MMBD. In the chaos following the fall of the Shah, Iranian (and world) oil production capacity was reduced by 3 to 5 MMBD between November 1978 and January 1979. This decline in capacity

initially had only a modest impact on world oil production and price because other countries, principally Saudi Arabia, increased their own production. But ultimately after Saudi Arabia announced its intention to reduce production there was a 75% increase in prices resulting from a disruption less than half the size of that considered here.

The price and quantity effects of a reduction in oil production capacity can be illustrated with a simple diagram. Figure 9 includes a typical short-run demand curve for OPEC oil exports and an upward sloping short-run oil supply curve, representing primarily the willingness of the OPEC producers to put more of their capacity into production at higher prices. Both the demand and the supply curves for disruption years are shown to be different from those in normal years.

The cut-back during the Iranian crisis or any disruption could be represented as a leftward shift in the supply curve. During the Iranian crisis the shift was triggered by a reduction in capacity but it need not be tied to a capacity change. The shift may simply represent a change in the willingness of the OPEC producers to utilize their productive capacity.

During disruptions the demand curve shifts outward, increasing demand at any given price. This shift occurs because world-wide inventories of crude oil and refined products are increased whenever future price or availability of oil becomes intensely uncertain. As a simple example, assume that in response to the disruption, all consumers and firms try to increase their oil inventories by only 5% over a 90 day period. Since world-wide petroleum inventories held at all levels of distribution amount to about 10 billion barrels²⁵, this example inventory build-up increases demand by 5.6 MMBD, a full 11% of WOCA consumption during those three months.

The relative inflexibility to adjust consumption and supply of crude oil over a short period of time (one year or less) is a second major factor

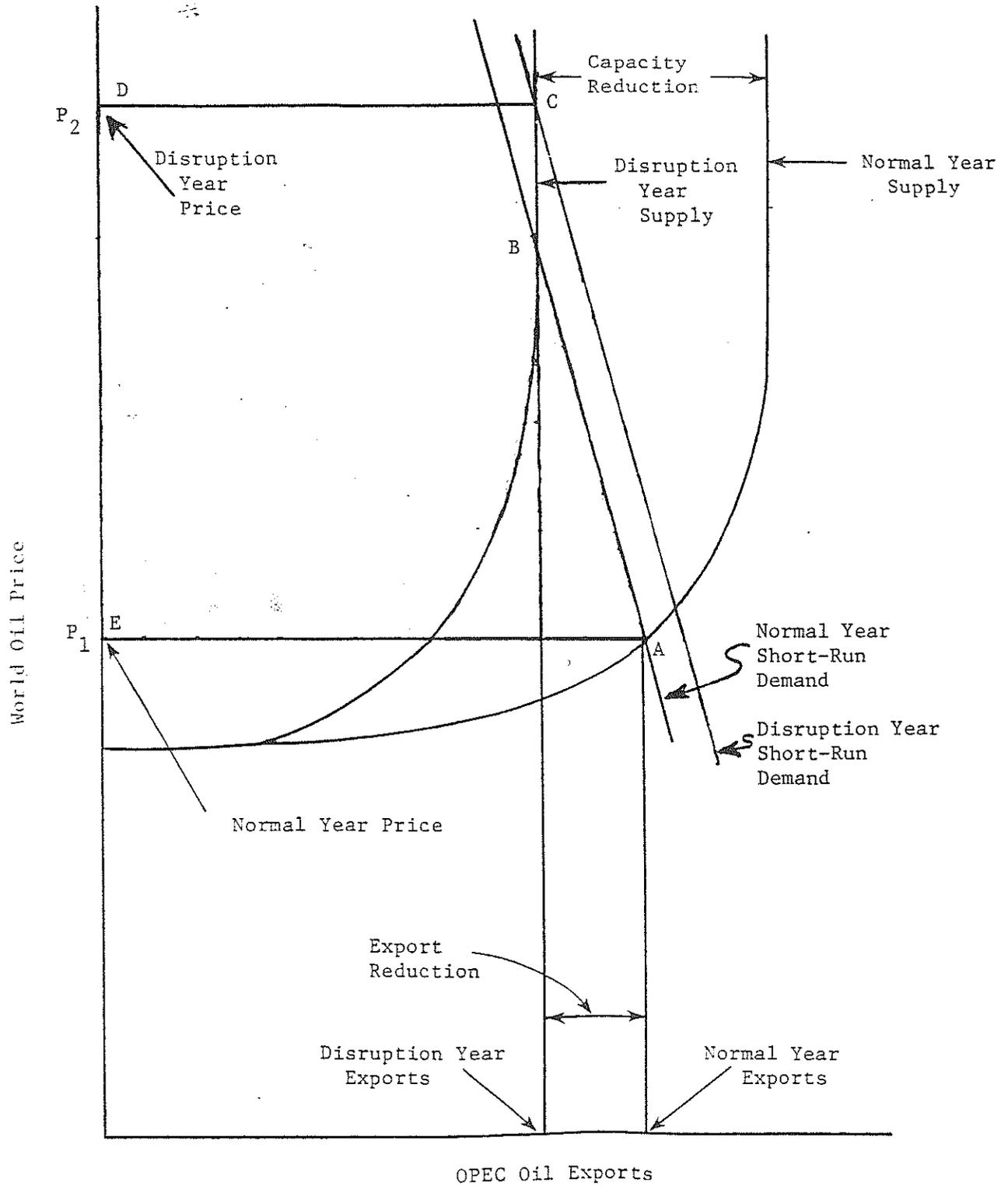


Figure 9 Effects of Supply Disruption on Oil Import/Export Market

underlying the supply vulnerability problem. Under normal conditions, the stock of oil consuming equipment and the usage patterns of that stock are gradually adjusted to expected oil price and availability. During a supply interruption, usage patterns can be adjusted rapidly but the capital stock cannot. Thus, oil substitution becomes progressively more difficult as additional supplies are curtailed. This relative inflexibility is reflected in Figure 9 by the steeply sloping supply and demand curves. Because the short-run import demand curve is steeply sloping, a disruption can lead to very large price increases. The lower the short-run import demand elasticity, the larger the disruption price impacts.

One factor tends to reduce the impacts of disruptions: the actual OPEC export reduction can be expected to be smaller than the reduction in capacity. This occurs because those OPEC nations not producing at their capacity prior to the disruption can be expected to begin producing closer to capacity during a disruption. The greater the excess capacity (the difference between production capacity and actual production) prior to the disruption, the smaller will be the reduction in OPEC exports during the disruption. For example, during the Iranian crisis, Iranian production fell suddenly by 5.2 MMBD. At the same time other OPEC nations increased their production collectively by 2.7 MMBD, leaving a net decline of only 2.5 MMBD.

Thus the amount of pre-existing excess capacity is a key variable in determining the impact of a given capacity loss. Excess capacity can reduce the impact of a disruption since some capacity could be put into production, compensating for the drop in production elsewhere, if nations with the capacity so choose. In the absence of much unused capacity, even small disruptions may lead to very large price impacts. Therefore, the price impacts of disruptions are apt to be more than proportional to their magnitudes: if oil markets are initially soft, a 2 MMBD capacity reduction may have relatively

little effect while a 4 MMBD reduction could have a profound impact on prices.

In summary, the magnitude of the price impacts will depend significantly on the amount of excess production capacity available, the willingness of the remaining producers to use this capacity, the short-run elasticity of supply and demand for oil, and the degree to which inventories are accumulated at the initiation of the disruption.

Figure 9 can also be used to illustrate the estimation of a lower bound on economic costs to oil importing nations of a supply disruption. A simple approximation of this lower bound is obtained by multiplying the import quantity by the change in price of imported oil. For example, a nation importing 2.5 billion barrels of oil per year loses \$75 billion of wealth per year if the price increases by \$30 per barrel. A more precise estimate is obtained as the area of the region ABCDE in Figure 9.

The actual economic costs of a disruption can be expected to be larger than those represented by Figure 9 because sudden oil price shocks may lead to unemployment of labor and capital equipment. This phenomenon is not included within the models nor in the calculations of economic loss conducted for this study. However, the subsequent Energy Modeling Forum study will explicitly address short-run macro-economic impacts of energy shocks.

Our analysis suggests that the cost to the oil importing countries of a disruption in OPEC production capacity depends primarily upon five factors: the magnitude of the disruption relative to the degree of pre-disruption excess capacity, the short-run elasticity of demand for oil imports, the pre-disruption quantity of oil imported, the rate of oil stock build-up or release during the disruption, and the willingness of OPEC nations to utilize excess capacity while the disruption is occurring.

There are several additional complications which limit the degree to which our analysis is representative of U.S. or OECD vulnerability.

Expectations about several factors affect consumption, inventory, and supply behavior during a disruption. These include expectations as to the length of the disruption and the magnitude of the loss in capacity, expectations which will be fed, not by accurate information, but by rumor, suspicion and conjecture. For example, during the Iran/Iraq war dependable information on even the size of the cut in production and capacity was never readily available. In the present study, it is assumed that the disruption is permanent, that it is known to be permanent, and that the size of the reduction in capacity is known with certainty to be 10 million barrels a day. Clearly these possibilities do not begin to bound the range of plausible future disruptions.

There is also considerable uncertainty as to the dynamics of the OPEC price response. During the disruption in 1979, members of OPEC appear to have followed the Rotterdam spot market in adjusting their prices, although, as one may observe from Figure 10, the adjustment did not occur instantaneously. The models included in this study calculate prices on a yearly basis and none differentiates spot from contract prices; thus, details on the dynamics of the price response are lost.

An additional dynamic issue cannot be addressed by the simple analysis. During a disruption we have seen world oil prices escalate very rapidly. But once the disruption was over, the price adjustments downward have come only slowly. This phenomenon, often referred to as a "ratchet effect", was evident after each previous price jump. Because of the ratchet effect, a disruption may have economic impacts for years after the disruption occurs; the total economic losses are significantly greater than those occurring during the disruption itself. Yet, since this ratchet effect is closely tied to pricing and production decisions among OPEC nations, the extent to which it will occur in the future is highly uncertain.

1981 DOLLARS PER BARREL

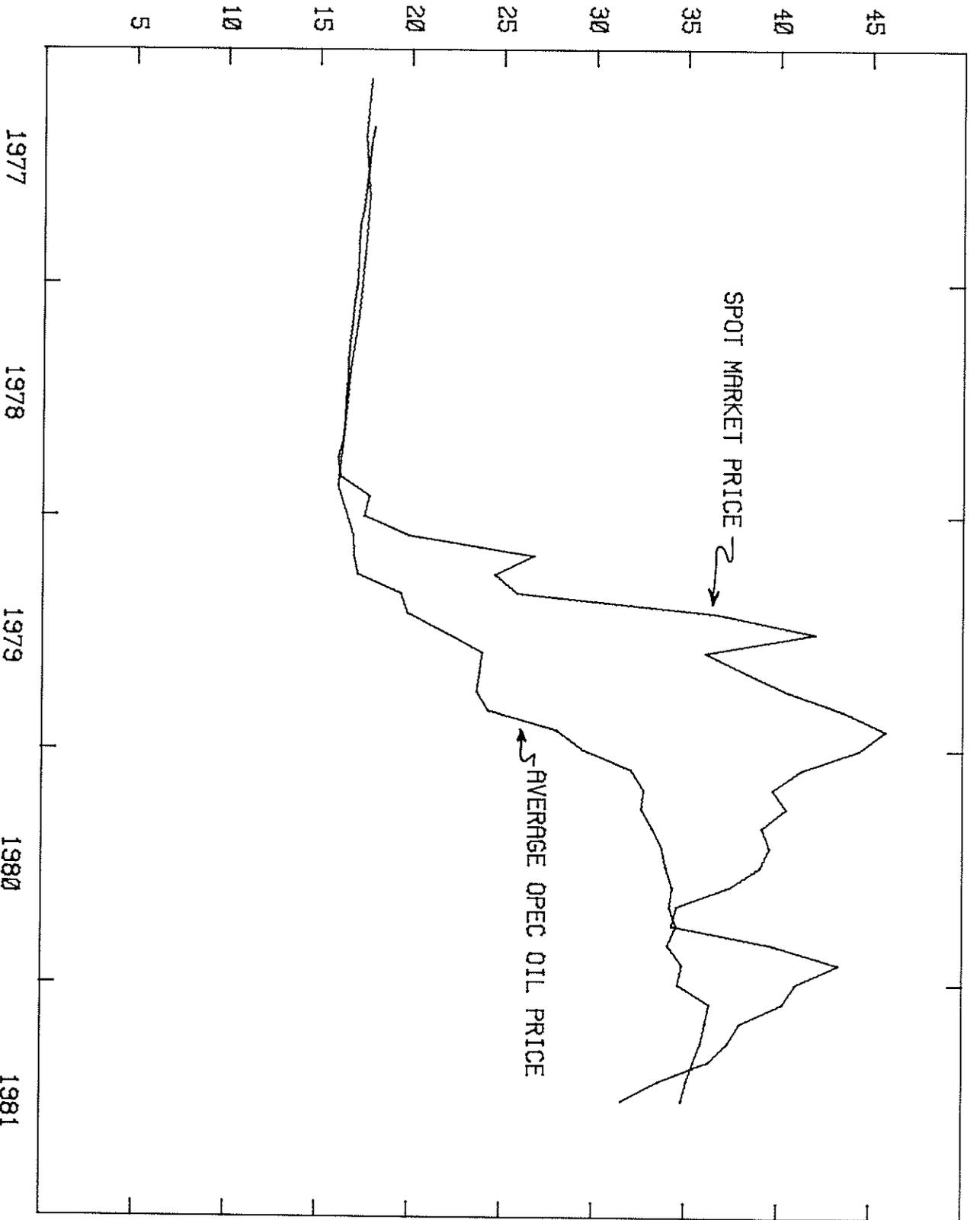


FIGURE 10
SPOT MARKET VERSUS AVERAGE OPEC OIL PRICE

Governmental policy responses can also have significant effects. These responses could include imposition of taxes or tariffs, price controls, release of oil inventories or stockpiles, or even the payment of a bounty for added imports of particular products. None of these policy responses was specified in the scenario design nor was any implemented in the models.

Finally, the conditions existing just prior to the disruption can also have a significant influence on its effects. If inventories are low or demand is rapidly growing, the consequence for oil prices will be dramatic. Conversely, if the world economy is entering a recession, or if oil stocks are full, then price impacts may be relatively mild. The minor world oil price impacts of the Iran/Iraq war provide an excellent example.

Stock acquisitions during the early 1980s were included in the EMF scenario design, but no uniform policy was set for their release during the 1985 disruption nor for any inventory accumulations at the beginning of the disruption. As a consequence, except for Gately, who assumed a 1 MMBD stock release, the modelers implemented the Disruption scenario without considering any stock changes at all. In consequence, the models probably underestimated the rapidity of the price jumps. Whether the magnitude of these jumps was underestimated or overestimated is not clear.

While there clearly are significant limitations involved in applying the models to evaluate our vulnerability, the models can provide some rough estimates of the magnitude of price adjustments to be expected for the first few years after a large disruption and can provide lower bound estimates to the economic losses.

QUANTITATIVE ESTIMATES

Three scenarios have been designed to examine the impacts of sudden supply disruptions. In each, the OPEC oil production capacity is suddenly reduced by

10 MMBD. Each scenario includes an assumption that the OPEC capacity remains at the reduced level indefinitely. This specification is not meant as a prediction of the expected characteristics of future disruptions. Rather we have attempted to understand the issues involved and to illustrate the magnitudes of those impacts which could occur during future disruptions. The three scenarios differ in the assumed energy demand environment. In the Disruption Scenario, Reference Case assumptions hold for all but OPEC capacity; in the Disruption/Low Elasticity Scenario low demand elasticity is postulated; in the Disruption/Oil Import Reduction Scenario an aggressive import reduction program is implemented well before the disruption occurs.

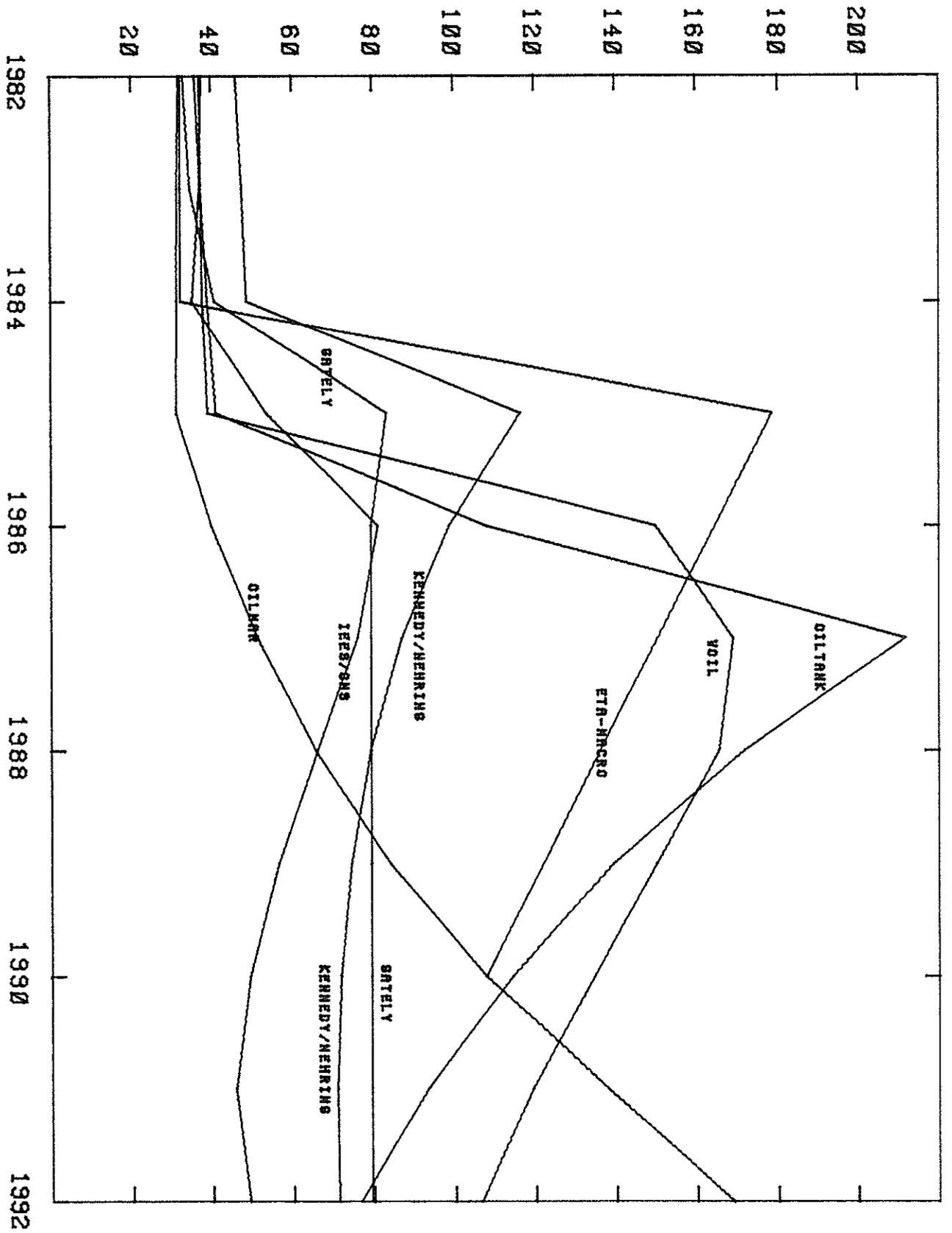
Comparative Price Impacts

Figure 11 displays price projections in the Disruption Scenario. Several features of this graph should be noted. First, while the maximum price impacts of the disruption vary greatly among the models, all suggest large price jumps. Four -- ETA-MACRO, OILMAR, OILTANK, and WOIL -- show maximum oil prices exceeding \$160 per barrel and three -- Gately, Kennedy/Nehring, and IEES/OMS -- show maximum oil prices between \$80 and \$120 per barrel.²⁶

The model results differ in their time pattern of price changes. Since the 10 MMBD disruption occurs abruptly but persists for many years, one would expect rapid price jumps followed by gradually declining real prices as demand and non-OPEC supply adjust to the elevated prices. However, in one of the simulation models -- OILMAR -- the maximum price increase occurs several years after the onset of the disruption. Virtually all project decreases in the disruption price impacts after the maximum price is achieved.

Since the Disruption Scenario only standardized the reduction in OPEC oil production capacity, the actual production rates may decline by varying amounts, depending on the pre-disruption excess capacity. In general, the

CRUDE OIL PRICE (1981 DOLLARS)



DISRUPTION CASE PRICES

Figure 11

short-run price impacts of the disruption are more influenced by the production decline than by the capacity drop.

Table 8 displays, along with other data, the changes in production and price projected using the various models. World oil price increases by between \$5 and \$29 per barrel on the average for each 1 MMBD sudden reduction in OPEC production. All but one project world oil price jumps between \$5 and \$12 per barrel for every 1 MMBD production decline.

The production declines are influenced, to a large extent, by the degree of excess capacity existing at the onset of the disruption. This is illustrated in the first two columns of Table 8. With the exception of IEES and OILTANK, the greater the pre-disruption excess capacity, the smaller OPEC production decline.

The approaches to analyzing disruptions differed widely among modelers and models²⁷. In results from three of the models OPEC is projected to produce at capacity during the disruption. If this were to occur generally, every MMBD of pre-disruption excess capacity would reduce the production decline during the disruption by 1 MMBD. Results from one model show excess capacity being reduced but not eliminated during the disruption. Two modelers assume that OPEC nations will keep their excess capacity constant during the disruption. For these models, the amount of pre-disruption excess capacity has no influence on the ultimate level of production during the disruption. Finally, one model shows excess capacity actually increasing during the course of the disruption. The actual behavior to be expected from OPEC nations during a disruption is central to evaluations of disruption impacts, as is their potential for reducing these impacts through the utilization of pre-existing capacity. As seen here, different assumptions as to OPEC disruption behavior lead to different projections of disruption costs.

Differences in the short-run price elasticity for oil imports can be

Table 8

KEY CHARACTERISTICS OF THE EMF 6 OIL SUPPLY DISRUPTION

Model	OPEC Excess Capacity in 1984 (MMBD)	OPEC Production Decrease ^a (MMBD)	Observed One-Year Import Elasticity	Maximum Increase in Price ^a (\$/bbl)	Price Increase per MMBD Production Decrease	Maximum Annual OECD Cost (\$B/yr) ^d
Gately ^b	3.9 ^c MMBD	7.3 MMBD	0.36	\$ 43 (1985)	\$ 6	\$ 310 B
IEES/OMS	8.2	9.3	0.33	51 (1986)	5	370
ETA-MACRO	5.0	5.0	0.13	143 (1985)	29	1010
WOIL	4.3	10.4	0.21	120 (1987)	12	710
Kennedy/ Nehring	0.0	10.0	0.45	67 (1985)	7	570
OILTANK	3.5	14.7	0.36	160 (1987)	11	1130
OILMAR	4.2	8.7	0.27	89 (1992)	10	720

^a All measured in the year of maximum price increase (shown in parentheses, column 5). All monetary figures in 1981 dollars. Each comparison represents the difference between the value in the Disruption Scenario and the corresponding value in the Reference Case.

^b Low elasticity disruption used for Gately to make his oil price elasticity comparable to all others.

^c In addition there is 1 MMBD of stock releases assumed for the Gately runs in 1985.

^d Estimated as the maximum price increase multiplied by the average of imports in the Disruption and the Reference Scenarios.

expected to lead to further differences in the disruption price impacts. Table 8 displays the short-run price elasticities for OPEC exports implicit in the model projections of price changes. Differences in the non-OPEC oil supply response and the WOCA short-run demand elasticities lead to a wide disparity in the short-run elasticity for oil imports. For example, in the Kennedy/Nehring model, the entire long-run non-OPEC supply adjustment to the disruption is implicitly assumed to occur instantaneously. At the other extreme, ETA-MACRO's low short-run import demand elasticity reflects the postulate that there will be no increase in non-OPEC oil supply. Although the proposition cannot be tested with our model results, the lower the import demand elasticity, the greater should be the price increase.

The longer range price implications of supply interruptions also vary among the models. In particular, the recursive simulation models show many years of price oscillations resulting from the 1985 disruption. These oscillations occur because the original price shock from the disruption motivates non-OPEC producers to increase their oil supply and consumers to cut back on demand. The net effect is a loosening of the oil market and a subsequent decline in prices. Over time, this price decline leads to a tapering off of non-OPEC supply, a resurgence in demand, and consequently, an increase in the demand for OPEC oil. As the market again becomes tight, a new cycle of price increases is initiated. A single disruption in the world oil market is projected by these model to lead to a longer-term pattern of turbulence.

Economic Losses

Economic losses to the oil importing countries can be estimated in two possible ways. A few of the models internally represent the impacts of energy prices on economic activity. For most however, such an output is not available. For these models we could estimate impacts only by calculating the

area ABCD in Figure 9. In order to maintain consistency, economic impacts for all the models were calculated using this latter procedure.

Table 9 includes data on the estimated annual disruption cost to the OECD nations in the year of maximum impact. These costs are immense; estimated maximum annual costs range between \$300 billion and \$1.1 trillion. Higher costs occur in the Low Elasticity/Disruption case.

The primary causes of variations in the projected economic losses are variations in the projected price increases. For the two basic disruption scenarios, the annual economic losses range from \$6 billion to \$8.5 Billion for every \$1.00 per barrel increase in the world oil price.

These projected economic impacts are probably too small. Even those models that include energy-economy interactions assume that the other factors of production (e.g., capital and labor) will accept lower returns, and will therefore remain fully employed during an oil shortage. This is an assumption not consistent with experience during previous oil supply interruptions. However, we have not been able to quantify this bias.

REDUCING VULNERABILITY TO OIL SUPPLY INTERRUPTIONS

The high economic costs of disruptions provide strong motivation to reduce vulnerability to oil supply disruptions. Three types of policies can be used to reduce our vulnerability to oil supply interruptions:

- reducing interruption costs by decreasing the pre-interruption level of oil imports,
- reducing imports during the crisis, and
- reducing the probability of disruption.

Our scenarios cast light only on those policies which reduce interruption costs by decreasing pre-disruption imports.

Table 9

**COSTS TO THE OECD OF A 1985 DISRUPTION
WITH AND WITHOUT IMPORT REDUCTION PROGRAM**

Model	Reference Case Disruption Costs (\$ Billions)	Conservation Case Disruption Costs (\$ Billions)	Reductions in Disruption Costs (\$ Billions)
Gately*	140	80	60
IEES/OMS	370	170	200
ETA-MACRO	1010	310	700
WOIL	710	180	530
Kennedy/ Nehring	570	310	260
OILTANK	1130	780	350
OILMAR	720	210	510

* In developing this table, we were not able to substitute low elasticity scenarios for the Gately model.

Import reduction measures undertaken prior to the disruption can reduce the short-run import demands and thereby can reduce disruption costs. Such measures may include increases in the fuel efficiency of energy using capital equipment (e.g., automobiles), alterations in capital equipment to allow use of coal or natural gas rather than oil (e.g., industrial boilers), or increases in the domestic production of oil or oil substitutes. However, measures taken in advance to reduce use of energy in unchanged capital equipment (e.g., turning down thermostats) may have no such favorable effect on the short-run import demand curves if they simply preempt measures that could be taken during a disruption.

Several long-run policy measures might motivate the reductions: import tariffs, energy use taxes, conservation programs, supply enhancement programs, quotas, and so forth. The study does not attempt to differentiate among these instruments. Rather, the Oil Demand Reduction and the Oil Demand Reduction/Disruption cases postulate a uniform reduction in the long-run and short-run demand functions, a reduction equaling 5 MMBD at the time of the disruption.

Figure 12 illustrates the role of measures which reduce the short-run import demand function. Besides the supply and demand curves from Figure 9, Figure 12 also includes a reduced import demand curve. Normal year and disruption year market clearing in the reduced demand case occur at points C and D, respectively.

Figure 12 illustrates that the price increase occurring during the disruption will be smaller in the presence of the import reduction measures than in the Reference situation. Likewise the actual reduction in OPEC exports will be smaller in the former case. Both effects occur because more excess capacity can be expected to exist when demand is lower.

Figure 13 displays the results of our scenarios, showing pre-disruption OPEC excess capacity and the maximum oil price increase during the disruption

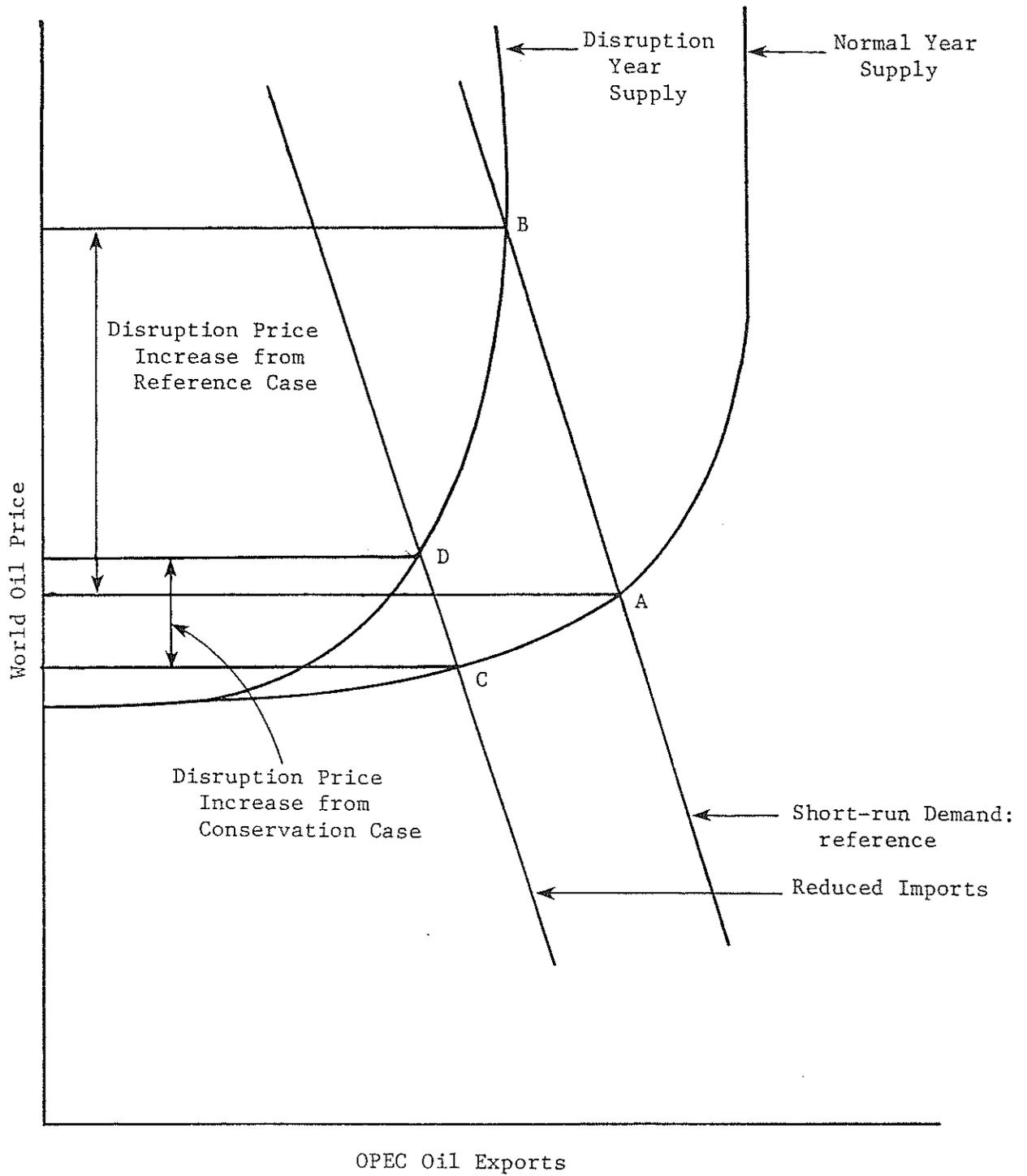


Figure 12 Effects of Import Reduction Measures on Disruption Imports

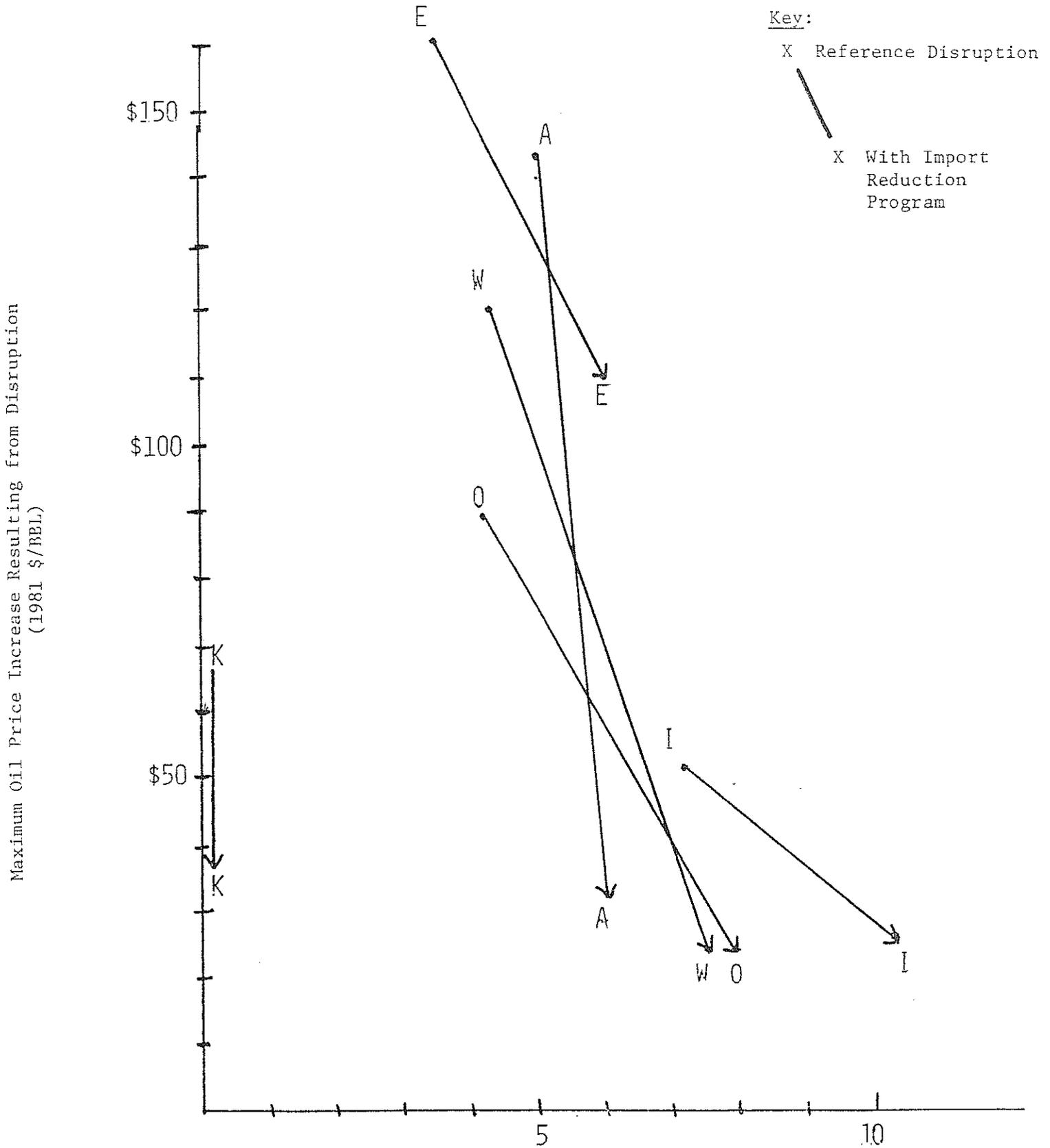


Figure 13 Effect of Long-run Import Reduction Program on Level of OPEC Excess Capacity Prior to the Disruption and the Resulting Price Increase *

* For a statement of model names corresponding to the letters, see Figure 8.

both in the Conservation/Disruption case and in the Disruption case. Each model illustrates that the long-run import reduction program leads to increases in OPEC excess capacity and important reductions in disruption price jumps. The magnitude of this effect in some models is quite striking. For example, in OILMAR (the symbol "O"), the 5 MMBD oil import reduction is met by a decrease in OPEC production of almost 4 MMBD and, consequently, a 4 MMBD increase in excess capacity prior to the disruption. As a result, the price jump during the disruption is reduced from \$90 per barrel to \$20 per barrel. Other models show smaller, but still large, moderating influences of reductions in oil imports.

Table 9 (shown previously) presents estimates of maximum annual disruption cost decreases associated with the 5 MMBD reduction in OECD oil demand.²⁸ The import reduction program reduces the projected disruption costs by more than 50 percent in most models. For some models, an even greater percentage cost reduction is projected. These large economic benefits of oil import reduction suggest the potentially high value of programs which reduce imports.

The scenarios have incorporated an explicit assumption that reductions in imports will leave OPEC production capacity unchanged. An alternative view is that import demand reductions will be met by equal reductions in OPEC capacity. If this were to occur, then no excess capacity would be created. However, even in this situation the economic impacts of disruptions may be cushioned. If the disruption occurs in the same country (or countries) whose pre-disruption capacity was reduced, then the size of the disruption will be reduced by an equivalent amount, completely offsetting any effects of the pre-disruption capacity reduction. In this case, whether or not capacity reductions do occur in response to oil import reduction programs will be irrelevant for evaluating the benefits of such programs. Our procedure will systematically overestimate benefits of import reduction programs only if the

disruption occurs in countries other than those reducing their capacity. Thus, our scenarios can be interpreted as embodying an assumption that either no OPEC capacity reduction will result from a reduction in OECD imports, or that any such reduction will occur in the country (countries) where the disruption occurs.

Encouragement of private-sector petroleum stockpiles and development of the Federal strategic petroleum reserve are often discussed as crucial policies for reducing impacts of disruptions. In our study we have not defined scenarios which allow us to directly examine such issues. However, we can use the simple analysis presented previously to extrapolate the benefits of such changes. This point can be illustrated through use of Figure 12. The release of stockpiles could be represented as a shift from the Reference short-run demand curve before the disruption to the Reduced Import Demand curve during the disruption. The net result would be that markets would clear at point D rather than at point B: price jumps during the disruption would be moderated.

The effects of increasing useable excess capacity and of releasing oil stocks during disruptions can be roughly quantified by reference to Figure 13. This figure suggests that each MMBD of additional excess capacity reduces the disruption price impacts by about \$20 per barrel. Note that this figure is well above the \$5 to \$12 range quoted for the average impact. The difference comes about because the incremental price impact associated with a relatively small change in the disruption magnitude is normally larger than the average impact measured for the entire production decline.

The similarity between releasing oil held in stockpiles and putting excess capacity into production allows us to infer that stockpile releases would likewise reduce disruption prices by about \$20 for each MMBD of oil so released. For example, 730 million barrels released over the course of a year

would average 2 MMBD of stock releases. This action could be expected to reduce disruption prices by around \$40 per barrel. Thus the amount of oil held in stockpiles and the quantity released during a disruption are extremely important determinants of disruption impacts.

CONCLUSION

The models were designed primarily to examine the behavior of the world oil market in the absence of supply disruptions; none was explicitly designed to study the effects of the precipitous decreases in oil production capacity such as specified in the disruption scenarios. The models do not consider a number of the factors that were shown during previous disruptions to be important. For example, full employment is implicitly assumed, private oil stock-building and depletion is ignored, gasoline rationing or petroleum product allocation schemes are excluded, and the interplay between spot markets and long-term contract markets is ignored. Thus, the models may misrepresent and many, we feel, underestimate the economic impacts of disruptions. However, the models generally display very high prices during a disruption. All show that long-run import reduction measures taken in advance of the disruption can greatly reduce disruption costs.

The results vary greatly among the models. These differences in projections depend primarily upon the magnitude of the disruption relative to the degree of excess capacity, the demand elasticity for OPEC exports, oil import quantities before the disruption, the quantities of stock released, and the willingness of OPEC nations to use their excess capacity during a disruption.

This section and the previous section have illustrated that the oil importing nations may benefit from import reduction programs, in both a non-disrupted and a disrupted world. This notion is an important one for policy purposes. Quantification of the benefits motivates the following section.

THE VALUE OF REDUCING OIL IMPORTS

While the preceding sections have painted a picture of increasing world oil prices and continuing vulnerability to oil supply disruptions, they have also suggested that measures to reduce oil imports can provide (1) reductions in the future world oil price; and (2) reductions in economic losses during supply disruptions. The consequent economic benefits stemming from import reduction, when expressed on a per-barrel basis are collectively referred to as the "import premium" for oil.

This section discusses the nature of the import premium and provides a quantification based upon the model results. Considerable variation in premium values results from different descriptions of consumer and producer behavior in the world oil market. Since we are fundamentally unsure as to the appropriate descriptions of producers and consumers, we must also accept uncertainty about the exact value of the premium. Moreover, we cannot expect this uncertainty to be resolved in the near future. However, our investigation does provide us with some general policy guidance and does suggest a possible range of values for the premium. Opportunities for displacing oil imports which incur costs near the bottom of this range should be seriously considered if economic efficiency is the goal. On the other hand, projects with costs above this range cannot be justified on the basis of the import costs which we consider here.²⁹ In the center of our range, there is a sizable grey area where other considerations must guide policy choices.

THE IMPORT PREMIUM

The import premium has two equivalent interpretations. It is the reduction in total import costs, over and above the world price of oil, caused by reducing oil imports by one unit. Equivalently, it is the economic cost,

over and above the world price of oil, of importing additional oil. In this situation an importing country can improve its well-being by reducing its imports to below free-market levels.

The import premium has at least two components. The first occurs because the world oil price rises when oil imports are increased. Oil importing countries must pay this increased price on all imports, not just on the added imports. Thus, additional imports increase the oil import bill by more than their price. The difference -- the price change multiplied by the import level -- is known as the "market power component" of the import premium.

In addition, the greater the level of imports, the greater the costs of a disruption, if it occurs. The effect of reduced imports on expected disruption costs gives rise to another component known as the "security component" of the import premium.

These two primary effects lead to secondary effects as well. Increased oil imports harm the balance-of-payments, thereby leading to exchange rate shifts which make all other imports more costly. Some analysts have suggested that the greater oil imports, the greater the domestic inflationary impact of an oil price increase. Furthermore, sudden oil price jumps can reduce GNP via unemployment, leading to recessions such as occurred in 1973-1974 and in 1979-1980. We have not addressed these secondary effects; for this reason our study may tend to under-estimate the total import premium.

The import premium thus measures the economic benefit to a nation of instituting programs to reduce oil imports, if those programs themselves do not introduce further inefficiencies into the economy. Costs of implementing such a program are not included in estimates for the market power component and therefore such costs must be weighed against benefits when using the import premium for policy analysis. Thus the market power component can be interpreted as the maximum (marginal) cost society should be willing to incur

in order to reduce oil imports below the level determined by competitive market forces, if economic efficiency is the goal.

Market Power Component

Our estimates of the degree to which oil import demand reductions influence world oil prices allow a simple static illustration of the market power component. Recall that in the medium run, each 1 MMBD oil import demand reduction leads to world oil price reductions of between \$0.90 and \$2.40 per barrel. Suppose that the U.S. were importing 6 MMBD of oil at \$35 per barrel. Then the daily import bill would be \$210 million. An import demand reduction of 0.5 MMBD (demand reduced to 5.5 MMBD) would reduce world oil price, or lessen the price increase, by between \$0.45 and \$1.20 per barrel, leading to oil prices between \$33.80 and \$34.55 per barrel. The import bill would then range between \$185.90 million and \$190.03 million per day. In this situation, the U.S. would reduce its total cost for oil imports by between \$19.98 million and \$24.10 million per day while reducing imports by 0.5 MMBD. The saving to the economy would range between \$39.95 and \$48.20 for each barrel of oil not imported. Those individuals reducing their imports would save about \$35.00 per barrel. The remainder -- \$4.95 to \$13.20 per barrel -- would be a savings captured by the remainder of the economy. This savings from import reduction not captured by the individuals reducing their oil consumption (or increasing their oil production) is the market power component, in this case \$4.95 to \$13.20 per barrel.³⁰ An identical logic would apply to increases in consumption, decreases in production, or any changes which increased net imports.

The market power component cannot be calculated as simply as suggested in the static example if the long-run demand elasticity greatly exceeds the short-run elasticity or if OPEC price administration slows the speed of price

adjustment. If both these phenomena are represented, unit import increase which continues over time leads to price increases which are small initially, grow to a maximum, and then decrease in the very long run. Since this behavior characterizes most of the models, some method is required to aggregate the various changes over time to obtain a per-barrel value of import reduction.

For this study we have generalized the measurement in a straight-forward manner. The market power component is calculated by estimating the sum of costs (or benefits) of the import increase, over and above the world oil price, discounted at the market interest rate³¹ (i.e., the present value[†] of costs or benefits). This sum is then divided by the discounted sum of shifts in the oil demand function to obtain the estimated import premium.

Security Component

The previous section (Oil Supply Interruptions) has described how a long-run program of import reductions can reduce the economic costs of a disruption, if it occurs. The estimates of these cost reductions can be used to compute a security component which can be added to the market power component to obtain a total premium.

The security component depends upon the probability assigned to the occurrence of an interruption. If the probability is zero, we are certain that an interruption will not occur and the security component will be zero. As the probability of a disruption increases, the security component increases proportionately, as shown in Figure 14.³²

We can illustrate calculation of the security premium with a simple example. Suppose that a disruption would cost the U.S. \$200 billion in a single year. Suppose further that with a 1 MMBD import reduction program, undertaken well in advance of the disruption, the disruption costs would be

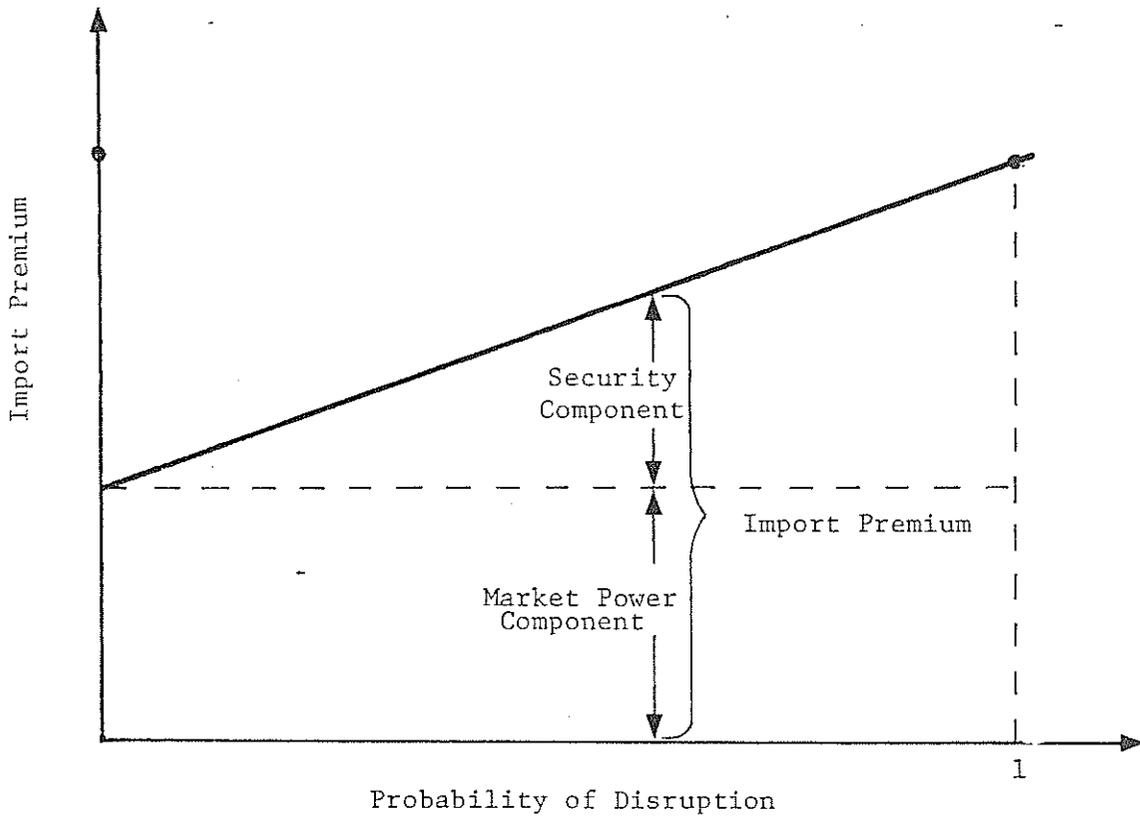


Figure 14 Two Components of the Import Premium

reduced to \$180 billion. The 1 MMBD demand reduction implies annual import reductions amounting to .365 billion barrels. If we knew a disruption would occur in a given year, and if reducing import demand by .365 billion barrels would reduce costs by \$20 billion, then it would be worth \$55 per barrel to reduce imports ($\$20/0.365$). Assume further that the market power component were \$10 per barrel. Then if we assessed a probability of 1.0 that a disruption would occur during a given year (i.e., we know it will occur), then the security component would be \$45 per barrel ($\$55-\10). If we assigned a zero probability, there would be no security component. Under an assumption that the annual probability of a disruption occurring were 5%, then the security component would be \$2.25 per barrel ($0.05 \times \45).

ESTIMATES OF THE PREMIUMS

In our study we have included one generic policy -- oil demand reduction -- which can be used to examine the implications of import reduction measures.³³

Table 10 presents the market power component, security component, and total import premium estimates under Reference assumptions.³⁴ Two sets of estimates are presented: the U.S. premium and the OECD premium. The U.S. premium is calculated by including only those benefits of oil import reductions received directly in the U.S. Its estimation includes an explicit assumption that U.S. reductions do not encourage other nations to likewise reduce their imports. The OECD premium includes one of two alternative assumptions. The U.S. or other OECD countries may be assumed to be willing to make their domestic policy choices based upon benefits and costs received by all OECD nations. Alternatively, the OECD premium can be envisioned as embracing an assumption that reductions in U.S. imports or imports of other

Table 10

IMPORT PREMIUM ESTIMATES^a
(1981 \$/bbl)

Model	U.S. Premium			OECD Premium		
	Market Power	Security ^b	Total	Market Power	Security	Total
Gately ^c	\$ 10	\$ -	\$10+	\$35	\$ -	\$35+
IEES/OMS	9	1	10	31	4	35
IPE ^c	8	-	8+	23	-	23+
Salant/ICF	8	0 ^d	8	27	0 ^d	27
ETA-MACRO	13	5	18	45	17	62
WOIL	7	4	11	24	14	37
Kennedy/Nehring	8	2	10	30	6	35
OILTANK	8	2	10	28	8	36
OILMAR	15	3	18	50	11	61

^a Security premium values based on a 5% probability of disruption occurring in any given year. This implies a 40% probability of such a disruption occurring at least once in 10 years.

^b U.S. security premium estimated by taking 30% of OECD security premium. For models without U.S. data, the market power premium is also taken as 30% of the OECD market power premium.

^c It was not possible to calculate a security premium for the Gately model since we used low elasticity cases instead of Reference assumptions in interpreting results from that model. The IPE model was not run for the Disruption/Oil Demand Reduction Scenario and therefore a security premium could not be calculated.

^d Because the short-run elasticity equalled the long-run elasticity in this model, we believe that this estimate is not meaningful.

nations will directly lead to the same proportional reductions in imports to all OECD nations.

The U.S. import premium varies between \$8 and \$18 per barrel (in 1981 dollars) with a median of \$10 per barrel. The largest of the two components is the market power component, which varies between \$7 and \$15 per barrel with a median value of \$8. The U.S. security component estimates vary from \$1 to \$5 per barrel, with a median value of \$2 per barrel.

In these security component calculations, the probability of disruption was assumed to be 5% per year.³⁵ Values of this component can be scaled upward or downward proportionately if probability assessments are different from our assumptions. For example, if we had assumed a 10% annual probability of a major disruption occurring, then the median and maximum security components would have been \$2 and \$10 per barrel respectively.

Similarly broad ranges appear for the OECD premium. The total OECD import premium ranges between \$23 and \$62 per barrel, with a median of \$35. These values are somewhat greater than three times the U.S. premium values because U.S. oil imports account for only approximately 30% of OECD imports.

We have presented ranges of import premiums rather than single estimates, primarily because the calculation of a single "correct" import premium lies well beyond the current state-of-the-art. Other studies which have estimated the U.S. import premium also indicate wide ranges of possible premium values. For example, Stobaugh and Yergin³⁶ have estimated a U.S. market power component between \$10 and \$35 per barrel. Hogan³⁷ has estimated a U.S. market power component between \$1 and \$5 per barrel and a total premium between \$2 and \$40, and Blankenship et. al.³⁸, have estimated a total U.S. premium between \$4 and \$10.

SOURCES OF VARIATION IN PREMIUM ESTIMATES

There is considerable variance in the estimates of the premium both in this and other studies. This variance has implications for the use of the premium in policy design and evaluation.

It would be tremendously convenient to have a single value of the premium. An exact value would make the evaluation of potential policies more straightforward from an economic efficiency perspective. Unfortunately, since we can make no claim to such a single value, economic evaluation of import reduction policies remains problematical.

We can, however, examine some of the sources of variation in our premium estimates. Within this context, we can evaluate the information our analysis does provide regarding appropriate import management policies.

The projected responses of OPEC nations to an import reduction program are crucial to the evaluation of the two components, whether these responses reflect normal market behavior or strategic responses designed to discourage import reductions. Large reductions in OPEC production in response to OECD demand reduction imply small reductions in price and hence a small market power component. However, such responses may create more excess OPEC production capacity and hence may lead to a larger security component. Conversely, if OPEC nations keep their production almost constant but reduce price significantly, then the market power component will be large and the security component small.

In some sense, then, there may be a trade-off in the estimates of the security premium and the market power component. Whether projected OPEC production cut-backs will decrease or increase the total import premium cannot be ascertained a priori.

A second aspect of OPEC behavior leads to uncertainty in the security component. The procedure used to calculate this component can be expected to

understate the value: although price increases occurring during the disruption may remain afterwards (remember the ratchet effect), the economic costs of these remaining price increases were excluded from the calculations. This omission implies that the security component is probably somewhat higher than the estimates presented here. How much higher, however, is unclear because the strength of the ratchet effect depends on the degree to which the OPEC nations successfully administer prices during a oil market glut.

A second issue is whether the U.S. or the OECD premium is to be used for U.S. policy purposes. The U.S. benefits directly from reducing its imports. But, in addition, all other oil importing countries benefit. Similarly, the United States benefits from import reductions in Japan, Germany, or other countries. Thus, the magnitude of estimated premiums depends significantly upon whose benefits and costs are counted and upon what assumptions are made as to cooperation among oil importing nations.

At first consideration it seems as if the U.S. should use the U.S. premium, Japan, the smaller Japanese premium, and Norway (as an exporter of oil) should use a negative premium. However, there are two reasons for each country using a larger premium, perhaps as great as the OECD premium.

First, policy makers in each country may be willing to consider benefits and costs accruing to other countries as they select their domestic policy options. This willingness could come from pure altruism or from deep beliefs that international cooperation is highly beneficial to all. In addition, policy makers, understanding the complex mix of continually occurring international negotiations, may believe that benefits conferred on allies through energy policy choices can be recaptured through other concessions granted in separate negotiations.

Second, policy makers may believe that actions by one country to reduce imports would lead to similar policy choices in other countries. For example,

in an extreme case one might believe that every 10% reduction in U.S. oil import demand would be matched by a 10% import demand reduction throughout the rest of the OECD. In this situation, any U.S. import reduction would be matched by an import reduction in other OECD nations equivalent to 2.3 times the U.S. reduction. Total benefits accruing to the U.S. per unit of U.S. import reduction will be roughly 3.3 times as great as would be the case if no foreign import reductions were induced. Thus, under this belief, the OECD premium would be appropriate even if only those benefits and costs accruing to the U.S. were included.

An additional source of variation relates to the assumed degree of consumer response to higher energy prices. The lower the demand elasticity for oil imports, the higher the market power component. And with lower demand elasticity, it could be expected that the security component would be higher as well. The economic benefits of import reduction measures in the low elasticity world are significantly higher than (perhaps double) those in the reference world.

IMPLICATIONS FOR POLICY

The import premium describes the value (above and beyond the world price of oil) to the U.S. or the OECD of import reduction measures. The magnitudes of the two components which were estimated within this study -- the market power component and the security component -- depend greatly upon several critical uncertainties. Thus, the magnitudes of these premiums remain quite uncertain, depending upon the models used and the specific assumptions included in the calculations.

Despite these irresolvable uncertainties, this investigation of the premium provides some guidance for import management. The range of estimates suggests that import displacements which can be obtained for less than \$8 per

barrel above the world price are almost certainly a net economic benefit to the U.S. Such measures should receive a high priority in U.S. policy. At the other extreme, import reductions which cost more than about \$20 above the world price could not be economically justified using the import premium components examined here.

One further qualification should be borne in mind. Information about the premium, no matter how specific, cannot help us choose among specific import reduction policy instruments. This choice involves issues which are entirely separate from the evaluation of the premium.

What we have seen in this discussion is that import reduction measures can indeed be valuable to the importing countries of the world. This deceptively simple observation suggests that we look critically at present policies which actually encourage or subsidize oil imports, and then develop additional import reduction policies going beyond reliance upon the free market.

THE TRANSITION TO NEW ENERGY SOURCES

Our focus to this point has been the evolution of the world oil market over the medium term: the next several decades. While events beyond the year 2000 are exceptionally difficult to predict, it is important to consider the longer term future, both because developments in the next two decades will have major impacts later, and because current decisions can be strongly influenced by perceptions about the distant future. In this section we are particularly concerned with the role that unconventional sources of energy, such as shale oil or biomass, will have in the oil market of the future.

The world energy economy has become increasingly dependent on low cost reserves of crude oil and natural gas. However, during the next several decades these reserves will be substantially depleted and new reserves can be expected to be more and more costly. Our scenarios suggest that the prices of conventional fuels will continue to rise.

The world economy can cope with these developments in a variety of ways: by improving the efficiency with which conventional fuels are produced, by developing the capability to produce unconventional fuels, and by reducing energy demands. An ultimate transition away from conventional fuels is an inevitable consequence of their depletable nature. But the timing and nature of the the transition remains highly uncertain.

This uncertainty arises from two sources. We do not know what technologies and resources will be available in the future, for example, whether oil shale will ultimately provide large amounts of inexpensive liquid fuels. The future will be shaped also by the values society places on different styles of living and economic organization. For example, some people view reduced energy consumption as desirable in and of itself, contending that such reductions would force society to reorganize its

activities in a more humane way. Others hold that our main concern should be with expanding energy supplies, contending that continuing economic growth is dependent upon continuing growth in energy consumption. Which, if either, of these views comes to dominate will determine the future of energy markets at least as much as will the progress of technology.

In this study we have not attempted to address either of these uncertainties. We cannot predict which of the several competing value systems will guide future choices on energy policy, nor can we predict the outcome of several decades of intense technological development. Our approach has been to investigate the consequences for the world oil market of alternative assumed future levels of unconventional oil supply. These alternative assumptions are designed to span the range from optimistic to pessimistic, representing the informed judgment of the working group. But it must be emphasized that they are assumptions, not predictions.

UNDERSTANDING THE TRANSITION

As we have noted, a central feature of our energy problem is the increasing scarcity and rising price of conventional fuels. Rising prices signal the potential profitability of new sources of energy and encourage investment in these sources. As prices rise, and as new technologies become proven, conventional oil will gradually be replaced by a variety of unconventional energy sources. Eventually, depletable energy sources will be replaced to a large extent by non-depletable sources, and energy scarcity will no longer force the price of energy to rise.

This verbal sketch of the long-run energy future is illustrated in Figure 15. In this highly simplified world all unconventional oil sources are treated as a single backstop source, with a constant production cost. Oil prices pass through three distinct phases in the Figure. Early on, only

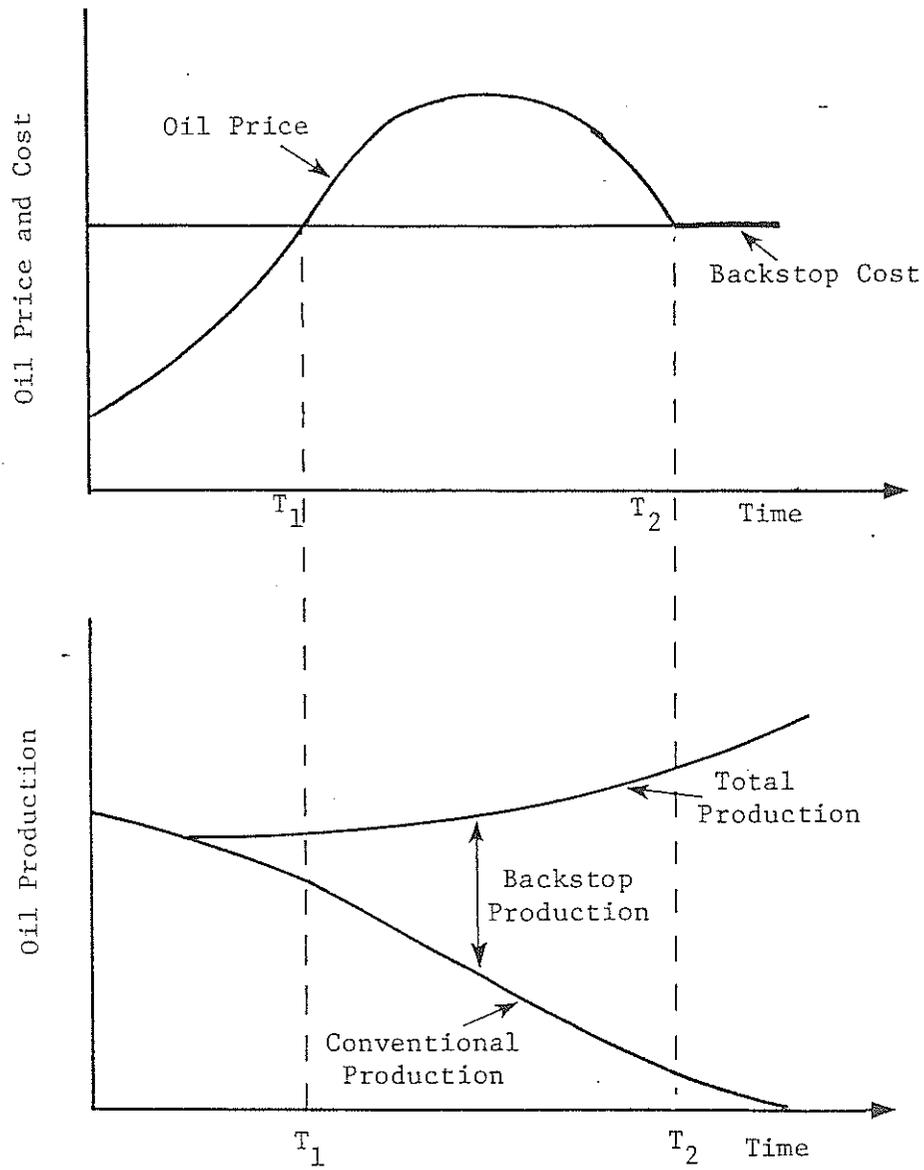


Figure 15 Transition to the Backstop

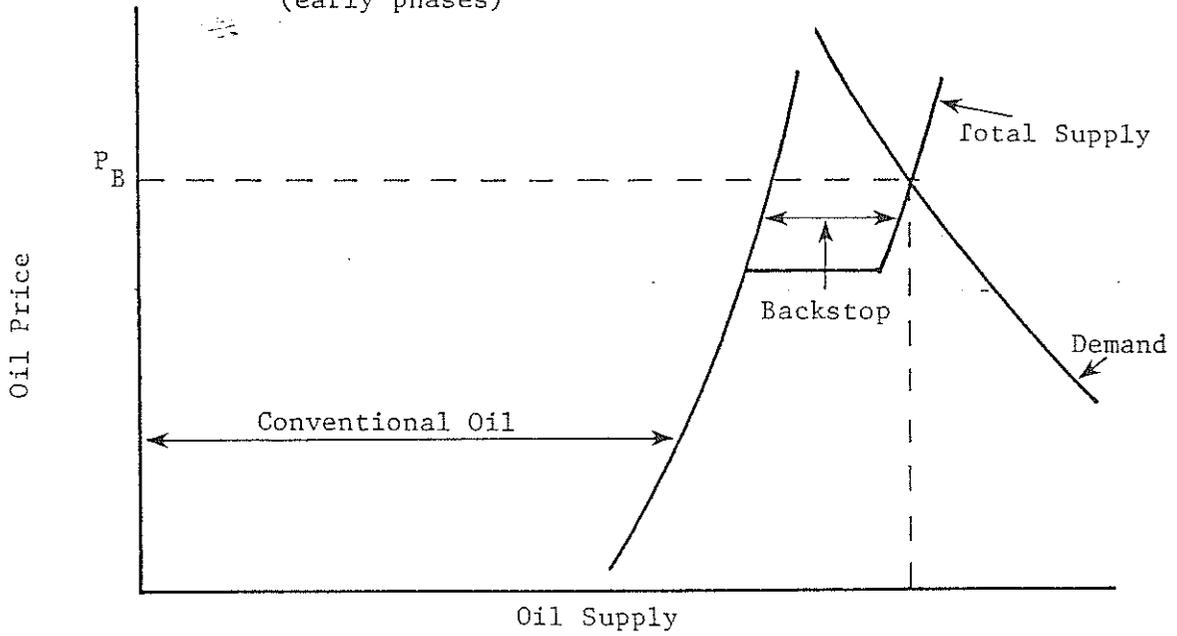
conventional oil is produced; its price rises as this resource is depleted. At time T_1 , when the price of conventional oil first reaches the backstop cost, backstop production begins. If, as seems likely, unconventional oil production capacity can increase only slowly at first (due to limited capital, environmental constraints, and so on) the price of oil may continue to rise above backstop costs.³⁹ If, eventually, backstop capacity grows to the point where it (along with conventional oil production) can meet demand at backstop costs, oil prices will decline to the level of those costs. This is the third phase, after T_2 in Figure 15, where backstop costs set the world oil price.

While the actual evolution of the world oil market will be more complex than sketched here, this discussion raises several points which will become important when we examine the model results. In the long run, how high the price of oil rises relative to the cost of alternatives will depend critically on the rate at which "backstop" capacity expands. The backstop may eventually provide a ceiling for oil prices, if backstop production, when added to conventional production, can meet world demand at the backstop cost. In the meantime, world oil prices may well overshoot backstop costs.

Under our scenario characterization of the backstop, the world oil supply has the form shown in Figure 16: at prices above or below the backstop cost, the quantity supplied responds smoothly to changes in price, while at prices equal to the backstop cost, a range of different supplies are possible. Figure 16 shows that supply and demand can intersect in two qualitatively different ways. In Figure 16A the limit on backstop production influences the world oil price, while in Figure 16B the backstop cost determines the price. The former case corresponds to the earlier time period (between T_1 and T_2) in Figure 15, while the former corresponds to the later period (after T_2).

Figure 16 also illustrates the world oil market impacts of changes in the backstop cost or production limit, such as occur between the various

A) Backstop Production Limit Influences World Oil Price (early phases)



B) Backstop Cost Determines World Oil Price (later phases)

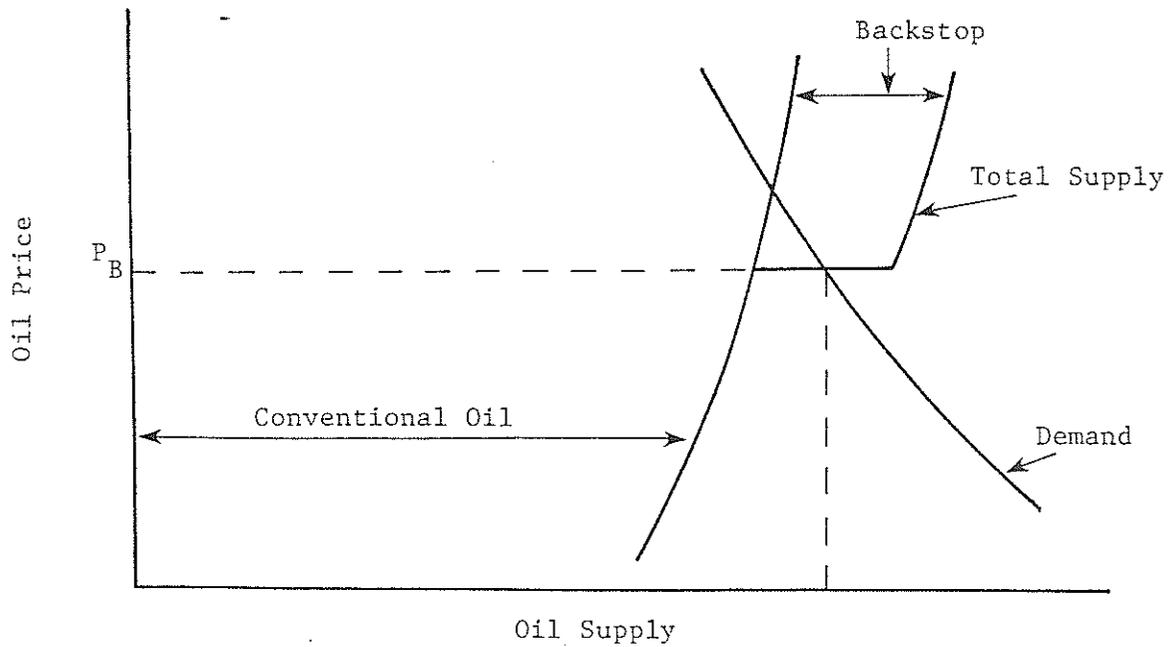


Figure 16 Market Clearing: Two Cases

scenarios. When the backstop cost determines the world oil price (Figure 16B), a cost decrease reduces the price, while an increase in the production limit has no impact. When the determining factor is the production limit (Figure 16A), a cost reduction has no effect on world oil price, but an increase in the production limit can reduce price.

While Figure 16 illustrates the basic interaction, the models are each more complex than indicated by these simple diagrams. For example, the simple analysis does not reflect the link between the profitability of backstop production and the rate at which backstop capacity expands. In several of the models, backstop capacity expands more rapidly, the greater is its profitability. In these models reductions in backstop costs will not influence production immediately, but will eventually show up in increased capacity and lower prices.

Another consideration not reflected by the simple analysis is the role of foresight on the part of producers or consumers. If backstop producers believe that backstop production will be profitable at some future time, they may invest in productive capacity in anticipation. If conventional oil producers believe that backstop costs will be reduced, they can be expected to shift their production plans, producing more oil currently and saving less reserves for the future. This shift would result in lower oil prices well before any backstop oil is produced. And if consumers have foresight, the opposite can occur: an expectation of future reductions in oil prices can lead consumers to invest in less energy-efficient capital, leading to relatively higher energy demands and prices in the near term.

The following sections describe our assumptions about backstop supply, and analyze these and other aspects of the world oil market response to alternative levels of backstop supply.

FUTURE UNCONVENTIONAL OIL SUPPLIES

Several factors make it difficult to estimate the level of unconventional oil production for future years. First, there is a great diversity of potential new sources of oil, and of energy generally. Second, the production rate from any one source will depend on the production from all other sources, the current and expected prices of oil, government policies, and a host of other factors difficult to quantify.

In the face of this complexity, for the purposes of this study we chose a drastically simplified description of unconventional oil supplies. All potential unconventional sources were aggregated into a single perfect substitute for oil called the "backstop." In any single year, we assume that the supply of backstop energy is described by two numbers: the cost of backstop oil, and the maximum production allowed in that year. If the current price of oil exceeds the cost of backstop oil, any amount up to this maximum could be produced. These maximum production figures were allowed to increase over time, so as to roughly reflect the complex evolution of the unconventional oil industry.

In the Reference Scenario, backstop oil was assumed to cost \$60 per barrel in 1979 dollars, which translates to \$71/bbl in 1981 dollars. None was available before 1995. The maximum quantity was assumed to be 1 MMBD in 1996, rising to 35 MMBD by 2020. In the Restricted Backstop Scenario the backstop cost was still \$71/bbl but the maximum production levels were half their Reference values. Finally, in the Technological Breakthrough Scenario, backstop costs were reduced to \$40 per barrel in 1979 dollars, or \$48/bbl in 1981 dollars; after the year 2010, significantly greater quantities are available (80 MMBD by 2020).

During the course of the study, a member of the Working Group with expertise in this area (Sheldon Lambert) undertook to estimate the production

potential of several specific and relatively well known unconventional energy sources. These include biomass, coal gasification and liquifaction, oil shale, and tar sands. Estimates are provided in Table 11. Table 11 underscores the variety of potential sources, the great uncertainty as to the future production from any specific source, the large quantities possibly available in forty years, and the small quantities to be expected within the next fifteen years.

These rough estimates do confirm the plausibility of our assumptions. Figure 17 allows us to compare the study assumptions with these estimates. Generally speaking, the rates set for the Reference Scenario fall near the upper end of that range, and those for the Restricted Backstop Scenario near the lower end. The optimistic assumptions of the Technological Breakthrough Scenario for the period after 2010 exceed the upper end of those estimates.

From one perspective, the estimates of Table 11 could be considered conservative. They exclude extensions of conventional supplies: tight gas, heavy oils, and so on. They also exclude all energy sources that only generate electricity. And, perhaps most important, they make no allowance for major technological breakthrough in the next several decades. On the other hand, the levels of production cited here represent massive financial investments, major political commitments, and possibly important environmental and social effects. A backstop industry of this size would rival the world's conventional oil industry of today.

QUANTITATIVE RESULTS

World Oil Price Effects

The model results confirm and allow quantification of several qualitative conclusions discussed above:

- Projected world oil prices significantly overshoot backstop costs.

Table 11

BACKSTOP SOURCES OF CRUDE OIL:
ESTIMATED PRODUCTION POTENTIALS FOR WOCA*
(MMBD)

	<u>1995</u>	<u>2000</u>	<u>2010</u>	<u>2020</u>
Biomass	1.2-2.5	1.5-3.2	2.1-5.0	2.6-7.8
Coal Gasification	1.0-3.5	1.3-5.1	2.0-8.0	2.8-12.3
Coal Liquefaction	0.4-1.4	0.6-3.1	0.8-4.9	1.0-7.4
Oil Shale	0.4-1.5	0.6-2.5	1.0-4.1	1.4-6.0
Tar Sands	0.5-1.3	0.7-1.8	0.9-2.4	1.1-3.5
	<hr/>	<hr/>	<hr/>	<hr/>
Total	3.5-10.2	4.7-15.7	6.0-24.4	8.9-37.0

* Source: Sheldon Lambert, Shell Oil Company

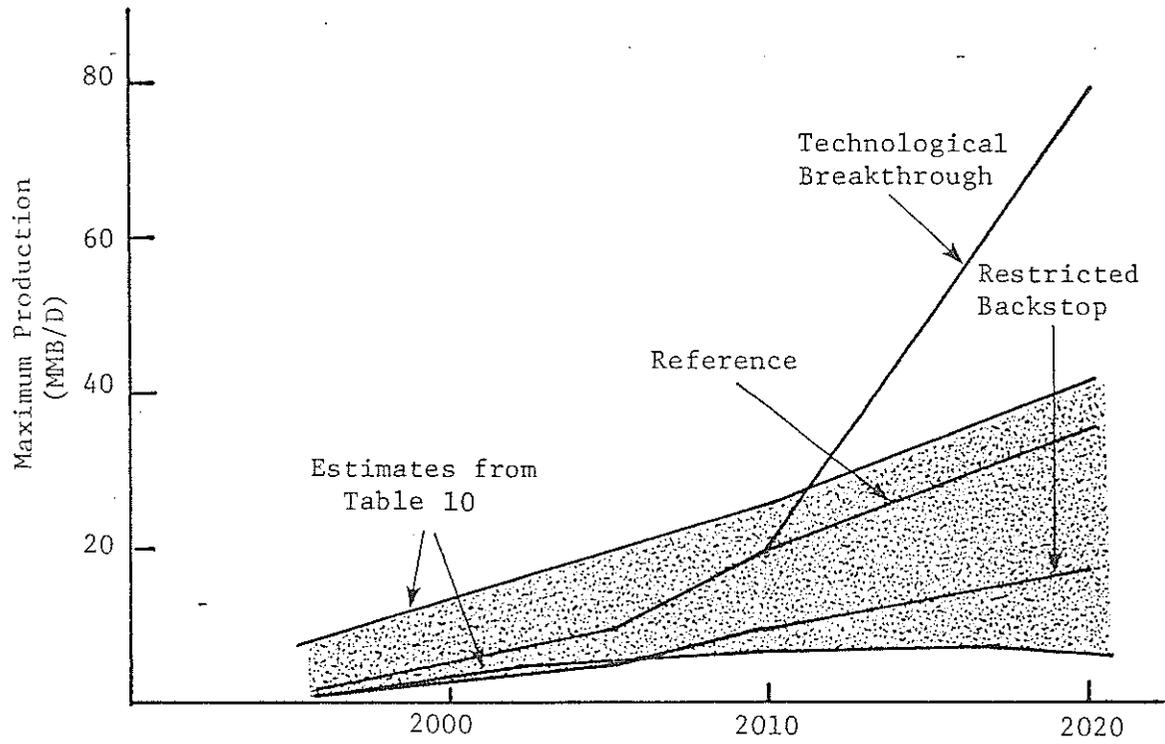


Figure 17 Backstop Production Limits: Reference, Restricted Backstop, and Technological Breakthrough Scenarios

- Massive backstop production rates would be required to limit oil prices to backstop costs.
- Expansion of backstop production rates would reduce world oil price.
- Producer and consumer expectations can influence world oil prices even before production begins.

The model results confirm our conclusion that the world price of oil is likely to rise well above backstop costs during the early part of the transition while oil demand (net of conventional supply) is growing faster than backstop production. Figure 18, which shows Reference Scenario prices to 2020, illustrates this pattern. Each model including post-2000 projections shows world oil prices above backstop costs at some point. Half show prices still climbing in the year 2020, while the rest project that prices would have peaked and subsequently declined to the vicinity of the backstop cost by that time. Thus, the mere existence of alternative energy supplies is not sufficient to limit world oil prices to backstop costs. Sufficient quantities must be available if such high prices are to be avoided.

How large a quantity of non-conventional energy is required in order to limit oil prices to backstop costs? While the precise quantities are unclear, they may be truly massive. In the Restricted Backstop Scenario, where 17.5 MMBD of backstop output is available in 2020, all models but one project the world price to continue climbing above backstop cost through 2020 and to exceed \$100 per barrel in that year. The exception, ETA-MACRO, includes an endogenously determined backstop output of 28 MMBD in 2020. Year 2020 projections of oil prices and backstop production quantities are graphed in Figure 19.

Maximum available backstop output in the Reference Scenario is 35 MMBD. In three models this quantity is sufficient to reduce prices to \$71 in 2020. But in three, it is not. Finally, in the Technological Breakthrough Scenario,

CRUDE OIL PRICE (1981 DOLLARS)

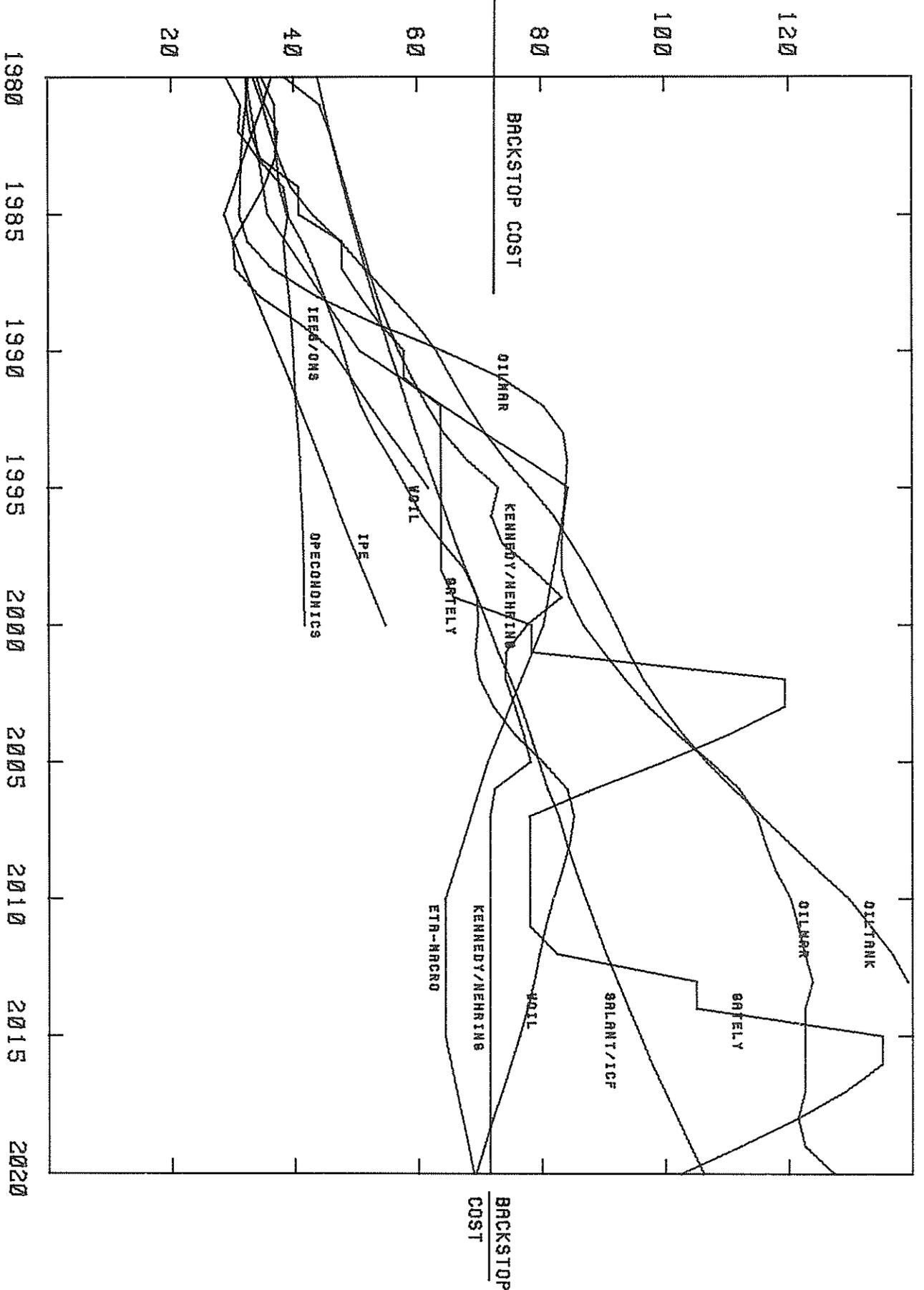
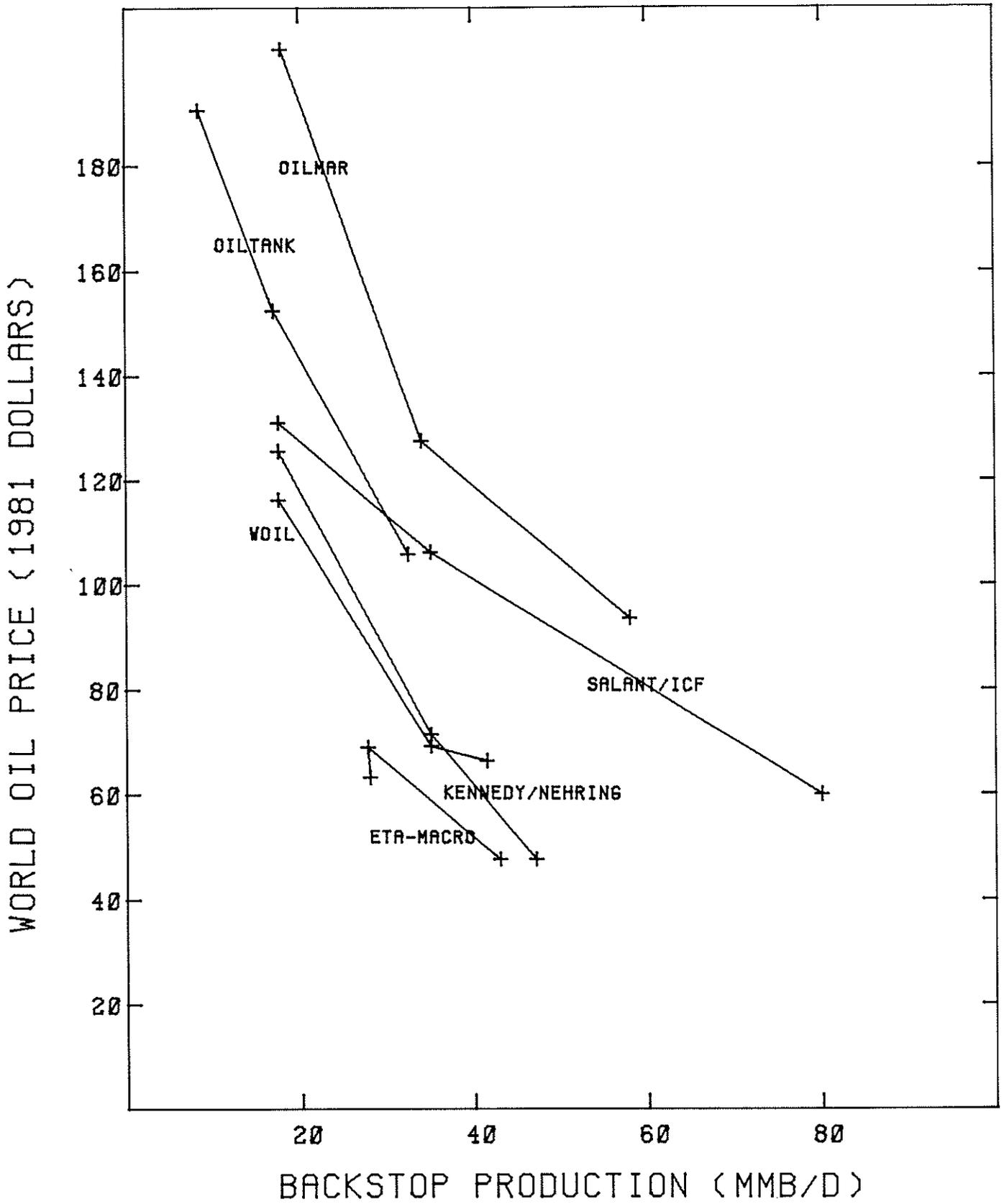


Figure 18 Crude Oil Price vs. Backstop Cost for the Reference Case



PRICE AND BACKSTOP PRODUCTION: 2020

Figure 19

backstop costs are lowered to \$48/bbl; up to 80 MMBD is available in 2020. In only two of the models do prices decline to backstop cost by 2020, despite production levels in excess of 40 MMBD. However, in all but one model prices are reduced below \$70 per barrel, as shown in Figure 19.

These results indicate that if an oil backstop is eventually to limit the world price of oil, its production must reach roughly the same magnitude as today's entire WOCA oil production--truly an enormous volume!

The backstop quantity, it should be noted, is in addition to the conventional crude oil production. By 2020 our projections suggest that the world will still be producing almost one-half as much conventional crude oil as is being produced today. Forty years from now the transition to new energy forms will still be ongoing. The era of oil is far from over.

Our results suggest that for the next forty years, backstop capacity will influence oil prices, as was illustrated in Figure 16A. The pattern is readily apparent in Figure 19, which shows year 2020 backstop production rates and the resulting world oil prices for the three scenarios. Increasing backstop production by 1 MMBD reduces world oil price by roughly \$1.80 to \$3.60 per barrel.

These results might at first seem to suggest that a 1 MMBD increase in backstop production rates reduce world oil price by more than would a 1 MMBD decrease in oil demand. This conclusion would be incorrect. We have estimated here the actual change in backstop production, not the change in the supply function for conventional plus backstop production. The previously stated estimates for price impacts of demand reductions rely upon projected changes in demand functions, not changes in quantities consumed. If we could evaluate the changes in supply function, then the price impacts of supply increases would be more consistent with the impacts of demand function changes.

The role of expectations about future price conditions is illustrated through the model results. Figure 20 plots world oil prices in the Restricted Backstop Scenario relative to prices in the Reference Scenario (the prices in the Reference Scenario subtracted from the prices in the Restricted Backstop Scenario). Three distinctly different responses to the restriction on backstop production are evident.

In one group of models (OILMAR, OILTANK, WOIL), prices are essentially unchanged until after 1995, when backstop production begins. These models include an assumption that none of the actors in the energy marketplace is assumed to have any foresight about future conditions. Thus prices stay at Reference levels until backstop production begins, at which point the market discovers the tight restrictions on backstop supply, and prices rise above their Reference levels.⁴⁰

In another group of models (Salant, Kennedy) prices are increased well before this date, while in ETA-MACRO prices are decreased. In the Salant model, all oil producers have perfect foresight about future market conditions, while in the Kennedy model only non-OPEC producers have such foresight. In both models, beliefs of producers about the future oil price influence their current decisions. If they expect backstop supply to be restricted, they will also expect future prices to be higher than otherwise. In this case, it is in their economic interest to postpone to the future some oil production planned for the present, since it will be worth more then. And with lower production, prices in the immediate future will be higher than otherwise.

In ETA-MACRO the opposite result occurs; it is consumers who are assumed to possess foresight about future market conditions. Consumers select energy-using capital so as to minimize costs over time. Less future backstop production means higher prices. With advance warning, consumers choose more

CRUDE OIL PRICE DIFFERENCE (1981 \$)

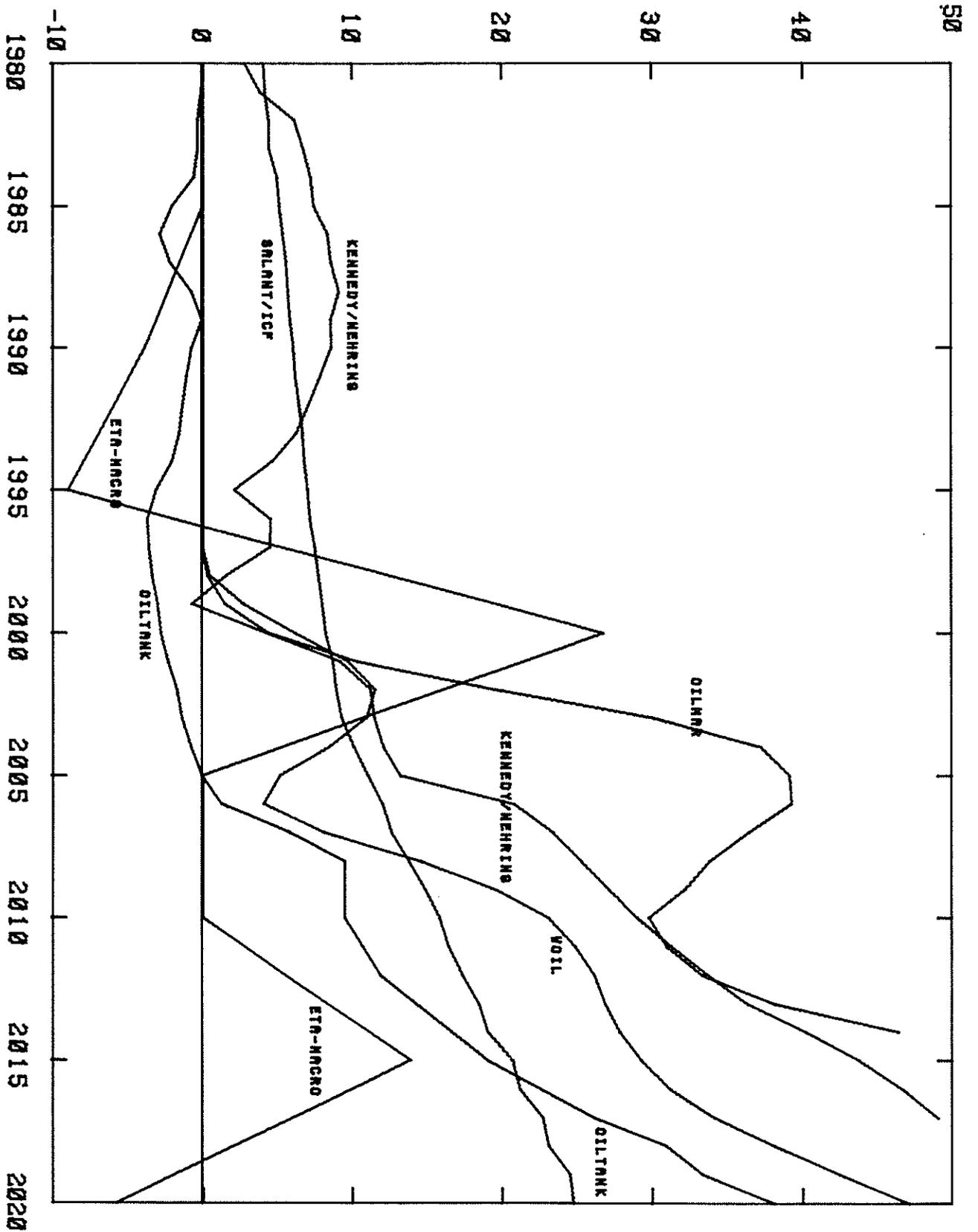


Figure 20 The Effect of Restricted Backstop Production Capabilities on World Oil Price

energy-efficient capital than in the Reference case. More efficient capital leads to lower demand and lower prices, at least until the backstop supply restriction dominates.

Effects on Distribution of Wealth

While the world oil price is an important indicator of the state of the energy economy, it cannot reflect fully the impacts of changing production and consumption patterns. Taken together, production, consumption, and prices will have a strong influence on the distribution of wealth between oil importing and oil exporting regions. In this section we look at the effects of increased backstop supply on the distribution of wealth, particularly between the OPEC and the OECD, and within the OECD between producers and consumers. We emphasize that while we can estimate the benefits of increased backstop supply, we have no information on the costs of achieving these goals. These costs include R&D expenditures, subsidy costs, and so on. Our results can indicate the stakes involved for various actors in the energy picture; they cannot by themselves tell us whether, for example, a particular synthetic fuels program is economically justified.

As we move from the Restricted Backstop to the Reference and then to the Technological Breakthrough Scenarios, backstop production expands, prices generally fall, the consumers' surplus in the OECD (and elsewhere) rises, and the surplus of conventional producers falls. This is illustrated in Table 12 which compares the Restricted Backstop Scenario to the Reference Scenario (left half of the table) and the Reference Scenario to the Technological Breakthrough Scenario (right half). Consumers gain \$700 billion to \$5,300 billion (present value of surplus) in moving from the Restricted Backstop Scenario the Reference Case, and another \$100 billion to \$5,700 billion from adding the Technological Breakthrough. The losses to conventional producers

Table 1.2

CHANGES IN OECD SURPLUS AND OPEC OIL REVENUES*
(Billions 1981 \$)

Model	Reference vs. Restricted Backstop				Technological Breakthrough vs. Reference					
	Consumer Surplus	Conventional Producer Surplus	Backstop Surplus	Total OECD Surplus	OPEC Revenues	Consumer Surplus	Conventional Producer Surplus	Backstop Surplus	Total OECD Surplus	OPEC Revenues
Salant	3,700	-800	60	2,900	-1,900	3,600	-600	1,000	4,000	-1,500
ETA-MACRO	700	-100	-200	400	-	1,800	-200	400	2,000	-
WOIL**	1,500	-400	-700	500	-1,500	100	-25	1,400	1,500	-600
Kennedy	4,100	-900	-1,000	2,200	-5,200	1,100	-100	600	1,600	600
OILTANK	700	-74	500	1,100	-700	5,700	-1,300	1,100	5,300	-4,200
Oilmar**	5,300	-800	-200	3,900	-4,000	1,200	-100	1,500	2,500	-1,900

* Discounted present value 1980-2020; 3% discount rate. See Appendix for details.

** Computed from U.S. data by multiplying U.S. imports by 3.29 and U.S. domestic production by 1.36.

are projected to be much smaller than consumer gains -- generally less than \$600 billion for either change. With two exceptions, backstop producers are also projected to lose profits in the change from the Restricted Backstop to the Reference Scenario: the resulting decline in prices more than offsets the rise in production. The Technological Breakthrough, on the other hand, is unambiguously valuable to backstop producers. The drop in backstop costs from \$71 to \$48/bbl and the expansion in production more than offset any loss from a decline in prices.

Table 12 also shows the change in the present value of OPEC oil revenues resulting from the expansion in backstop supply. In all cases, OPEC loses revenues as backstop supply expands. With but few exceptions, the loss sustained by OPEC is less than the increase in OECD surplus. This result points to the possibility that cooperation between oil producing and consuming nations could be in their mutual interest.

Our projections suggest that the discounted value of OPEC oil revenues over the period from 1980 to 2020 may total \$12 to \$18 trillion (constant 1981 dollars). Table 12 shows that a loss of about \$1 to \$2 trillion, or roughly 10 to 20 percent of the total, can result from substantial increases in backstop supply. The effects on OPEC, on oil consuming nations and on the world economy of this potential wealth transfer could be significant, but are difficult to predict.

MODEL CAPABILITIES AND LIMITATIONS FOR ANALYZING THE TRANSITION

With the partial exception of ETA-MACRO and Salant/ICF, none of the models was explicitly designed to analyze the transition to alternative energy sources. Each focuses on the production and consumption of conventional resources over the medium term. As a consequence, all the models required exogenous assumptions about the backstop. In most, non-conventional energy

production rates closely followed the limits specified in the study design. However, in OILTANK and ETA-MACRO, investment in backstop capacity is a function of current or anticipated backstop profits. This latter approach is to be preferred to an exogenous specification of the backstop supply, as it allows examination of the effects of basic forces governing backstop supply. But even these analyses are quite speculative. Thus, taken as a whole, the results of this study allow us to draw conclusions about the sensitivity of the oil market to the level of backstop supply, but give us little insight into the future of the backstop industries themselves.

Another important limitation arises from the difficulty of projecting forty years into the future. For example, energy demand in 2020 will depend not only on prices, economic activity, and the relevant elasticities, but also on the existing capital stock and on the future organization of the economy. Since those underlying factors could change dramatically in the next forty years, historical estimates of relationships may prove terribly unreliable.

The extent to which other fuels may be substituted for oil is another important determinant of long-run oil demand. The models vary widely in their capability to treat this issue. One group (OILMAR, IPE, OILTANK, Kennedy) explicitly represents only oil and not other fuels. Interfuel substitution can be reflected crudely in these models by an elasticity of demand for oil higher than would be appropriate for all energy. But this provides at best a crude approximation. In a second group of models (Gately, OPECONOMICS) some or all forms of energy are assumed to be perfectly substitutable. This exaggerates the potential for substitution between fuels. Finally, a third group (IEES, WOIL, ETA-MACRO) include oil within the context of supply and demand for all energy types. In these models the possibilities for interfuel substitution are represented explicitly. We feel models in this last class show most promise for examining long-run issues.

SUMMARY

The world economy is not running out of energy; rather, the less costly sources of oil are becoming scarce. We are in the midst of a transition from cheap depletable energy sources to renewable or non-depletable alternatives.

During this transition period the price of oil may rise well above the cost of alternatives. Depending on how much alternative supply is available, this overshoot could be major or minor. But unless massive quantities of backstop energy are available, we can expect oil prices to exceed average production cost of these alternative energy sources.

The availability of alternative energy sources will have a major impact on the economies of every region in the world. Oil-consuming nations stand to gain significantly from any actions that expand future supplies. Likewise, oil-producing nations stand to lose if technological advances increase world oil supply. Nations that produce alternative fuels during the transition will reap large profits as oil prices overshoot the cost of alternatives. The economic consequences of alternative choices may be great.

IN CONCLUSION

We have attempted to apply ten of the most prominent models of the world oil system to a number of issues central to energy policy and planning. In this exercise we have seen that the models are particularly useful for examining medium-run trends in the world oil markets and far less useful for examining short-run adjustment dynamics. As a class, they are relatively weak for examining sudden shocks caused by supply disruptions. Thus, further research and modeling efforts will be required to develop tools effective for examining processes of sudden adjustment.

For very long-term analysis, the models have been shown to be useful for evaluating the world oil consequences of alternative backstop growth paths but not useful for projecting these paths themselves. Most models do not examine all energy carriers but either include only oil or all energy as an aggregate. Thus, most cannot explicitly examine the role of interfuel substitution as it relates to very long-term world oil trends.

For projecting medium-run trends, however, the model limitations are of less consequence. And the models as a class do represent those elements of the world oil system which seem most important for mid-range analysis, although differences among the models still exist, representing differences in theory or data about the future evolution of the world oil markets.

Use of the models has underscored the continuing uncertainty about future oil market conditions. We have identified very plausible situations in which constant dollar world oil prices will rise only slowly and other disturbingly plausible situations in which prices could suddenly explode, perhaps tripling or quadrupling within a one to two year period.

Even with the great differences among the models, we have been able to reach a number of conclusions robust across the models and scenarios. These conclusions relate to the future trends in the world oil market, the impacts

of possible supply interruptions, the value of import reductions, and the transition to alternative energy sources.

The overall conclusions are not happy ones for the oil importing nations, but they do suggest the importance of aggressive energy policy actions. If these models and scenarios do correctly represent likely world oil futures, then we can expect the real price of oil to decline or remain stagnant for several years but then to rise significantly, the era of oil to continue, the oil importing nations to remain dependent on OPEC for oil supplies and vulnerable to interruptions of those supplies, and short-run or long-run import reduction measures, if taken, to significantly benefit the oil importing countries.

FOOTNOTES

- 1 The real price is the price adjusted for inflation. See Appendix B for a definition of this concept and some other economic concepts used in the discussion. The first use of a word listed in Appendix B will be marked with the symbol †.
- 2 OECD premium values ranged between above \$23 and \$62 per barrel. The central seven of nine results range between \$27 and \$61 per barrel (all 1981 dollars). U.S. premium values range between \$8 and \$18 per barrel for both the set of all nine results and for the central seven.
- 3 This assumes a decrease in OPEC production levels from below market clearing rates. Reductions in OPEC production to meet demand reductions of course do not have the impact of increasing prices but rather of avoiding price decreases.
- 4 The Energy Modeling Forum is administered at Stanford University within the Departments of Engineering-Economic Systems and Operations Research and under the auspices of the Institute for Energy Studies. Funding is provided by the Electric Power Research Institute, the Department of Energy, and the Gas Research Institute.
- 5 The complete report will be published by Ballinger Publishing Company under the title: World Oil.
- 6 The fourth EMF study, "Aggregate Elasticity of Energy Demand" extensively studied demand elasticities for the aggregate of all energy. Oil elasticities were not separately examined.
- 7 In running the Salant/ICF model, ICF incorporated a non-stationary linear demand curve designed to "mimic" slow adjustment of demand to price changes.
- 8 A more complete discussion of this issue as it applies to the Gately model appears in footnote 14.
- 9 The Salant/ICF model need not be run under these assumptions. These specific assumptions were selected by ICF as they ran the model.
- 10 In IPE key decisions are investments in exploration and development.
- 11 Equivalently, the Eta-Macro model can be seen as projecting OPEC exports to OECD as an increasing function of oil price. The relationship shifts exogenously over time to accommodate increased non-OECD oil consumption.
- 12 The Primary Energy elasticity is calculated with prices and quantities measured at the port of entry, mine mouth, or wellhead.
- 13 The price of oil to which we refer is neither an OPEC contract price nor a spot market price, but rather an average of the various prices at which Saudi Arabian light crude might be sold. For a detailed discussion of oil price definitions and historical data, see Chapter ?.
- 14 In reporting results for the Gately model, a problem of consistency among inputs was recognized. The study design allowed modelers to choose a standardized oil demand elasticity or a standardized elasticity of demand for aggregate energy. Gately chose the latter when running his model. Since the

Gately model incorporates an implicit assumption that all forms of energy are always perfect substitutes for one another, a standardization of energy price elasticities among models implies that the oil price elasticity in the Gately model will be significantly higher than in models which treat the various energy forms as imperfect substitutes or than in the oil-only models. Running the Gately model with an aggregate energy demand elasticity of -0.4 implies an oil demand elasticity of about -1.0, a figure far higher than specified in the study design. The net result was that the Gately projections were judged to be based upon inputs not consistent with those chosen for the other models.

Rather than discarding the Gately results or simply accepting the inconsistency, we have chosen to use the Gately Low Elasticity Case in place of the Reference Case when reporting the results for all Tables and Figures except Figure 8 ("Scenarios and Price Results"). This substitution results in an implicit oil price elasticity of about -0.7, a figure far closer to that used in the other models. Whenever possible, we substituted cases including a low elasticity of energy demand. Throughout this report, the following substitutions have been made for the Gately model only:

Low Elasticity (3)	for	Reference (1)
Oil Demand Reduction/Low Elasticity (4)	for	Oil Demand Reduction (2)
Disruption/Low Elasticity (9)	for	Disruption (7)

Unfortunately, a more complete set of substitutions was not possible.

Mathematically:

$$\begin{aligned}
 & \text{(elasticity of demand for oil)} = \\
 & \text{(energy quantity/oil quantity)*}(\text{elasticity of demand for energy}) \\
 & - \text{(non-oil quantity/oil quantity)*}(\text{elasticity of supply of non-oil}).
 \end{aligned}$$

For 1980, with an energy elasticity of demand of -0.4, this equation becomes:

$$-1.0 = 2.0*(-0.4) - 1.0*(0.2)$$

With an energy demand elasticity of -0.25, this becomes:

$$-0.7 = 2.0*(-0.25) - 1.0*(0.2).$$

The figure of 0.2 for the elasticity of supply of non-oil is based upon the Gately model elasticity of supply of all non-OPEC energy of 0.2. Notice that changes in the value of this elasticity would not change our conclusion that the Low Elasticity scenario incorporates an oil demand elasticity closer to the study design than does the Gately Reference run.

15 In making the runs, all costs and prices were specified in 1979 dollars. However, all prices are reported in this summary in terms of 1981 dollars. To convert from 1979 dollars to 1981 dollars, all prices were scaled upward by the increase in the GNP implicit price deflator between the first quarter of 1979 and the first quarter of 1981. Thus all model-reported prices were scaled upwards by a factor of 1.19 for this summary.

16 The prices in Figures 1 and 2 differ from each other even for 1980, the year in which the runs were conducted. This occurs primarily because the models have been benchmarked differently. Some, such as Salant/ICF and Kennedy/Nehring do not use recent prices as inputs to the models. Most of the others do use recent price data but are benchmarked at some year prior to 1980.

The high prices in the Salant/ICF model seem to occur because ICF imposed constraints on maximum production rates of OPEC, LDC, and backstop oil. The frequent imposition of such flow constraints by users of this model is not uncommon. While in the Reference Case these exogenous constraints do not bind for more than a decade, their effect on price is felt much earlier because this model includes an assumption of perfect foresight (see footnote 19).

17 In developing the analysis underlying Figure 3, oil demand is projected separately for the OECD and for the combination of OPEC and LDC's. Oil demand for each group is benchmarked at actual 1980 levels. An income elasticity of 1.0 is used for the OECD nations and of 1.2 for OPEC and the LDC's. Average levels of economic activity grow at 3% annually for the OECD and at 5% annually for the LDC's and OPEC. The long-run price elasticity is assumed to be -0.6. However, demand is assumed to adjust slowly in response to price changes, with only 10% of the remaining long-run adjustments to price occurring in each year. The adjustment process is initiated in 1973 under an assumption that 1972 was in long-run equilibrium.

The equations used were as follows:

$$D(t)/D(1980) = [X(t)/X(1980)] [Y(t)/Y(1980)] \quad \text{for OECD}$$

$$D(t)/D(1980) = [X(t)/X(1980)] [Y(t)/Y(1980)]^{1.2} \quad \text{for LDC and OPEC}$$

$$X(t) = X(t-1)^{0.9} [P(t)/P(1972)]^{(0.1)(-0.6)}$$

$$X(1972) = 1.0$$

$$P(t)/P(1972) = 1.13, 2.67, 2.59, 2.71, 2.62, 2.36, 2.87, 4.00 \quad \text{for 1973, 1974 ... 1979, 1980 respectively}$$

$$= 4.00 \quad \text{for 1980 and later}$$

where,

t is time, D(t) is demand at time t, Y(t) is the level of economic activity at time t, P(t) is oil price at time t.

The supply estimates begin with actual 1980 quantities produced. These were estimated to equal the 1980 consumption plus 0.6 MMBD to account for the increase in oil stockpiles during 1980.

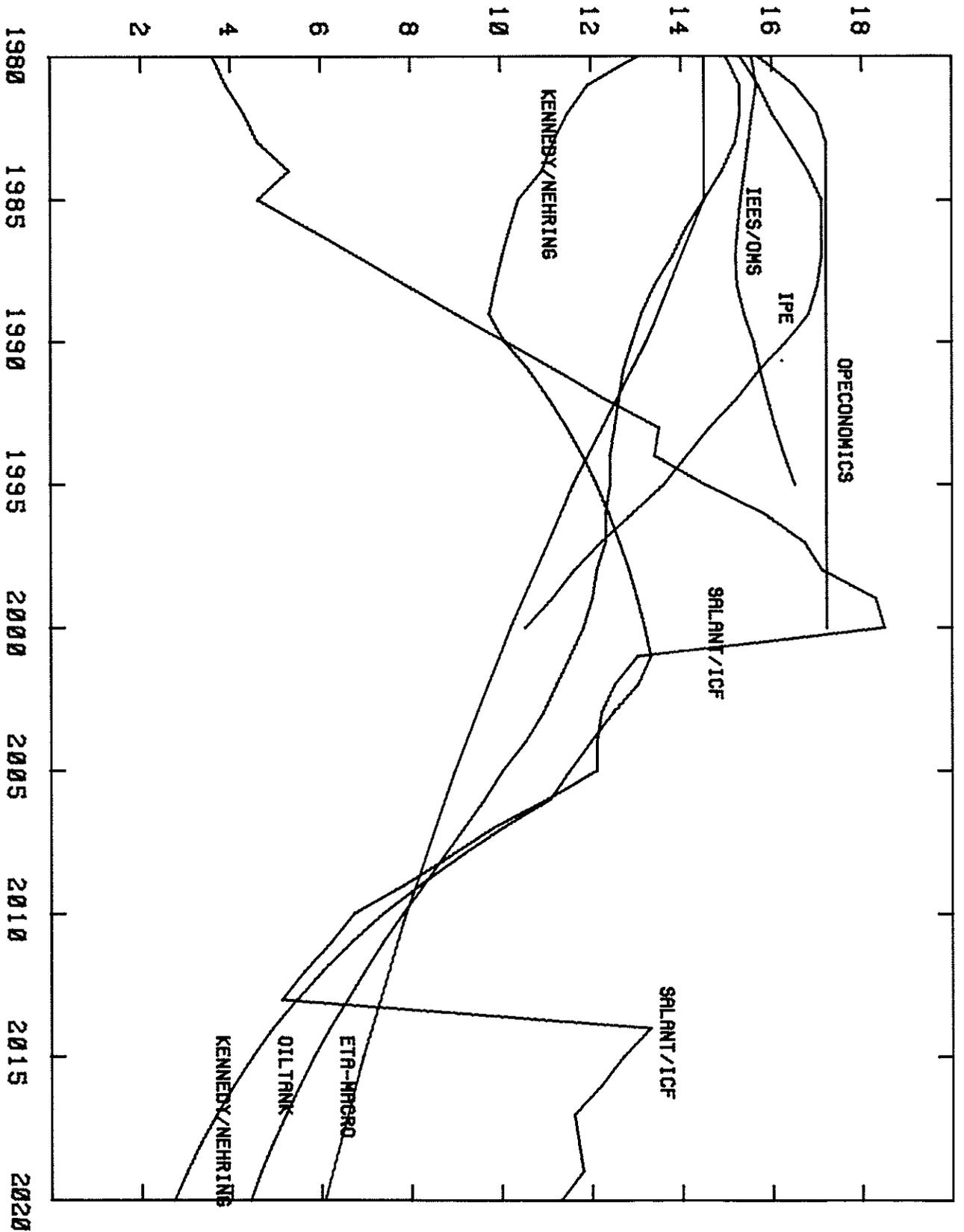
18 These graphs were derived by subtracting OPEC production from WOCA production. OPEC production (and hence non-OPEC production) is not available beyond 2000 for the Kennedy/Nehring model because of a reporting error.

19 In these particular runs of the Salant/ICF model, ICF assumed that firms face constant per unit extraction costs up to some exogenously determined maximum extraction rate (which cannot be exceeded). Constraints were imposed on production by OPEC, the LDC's, and the backstop; in particular, for conventional resources, the maximum ratio of production to remaining resources was set at 0.10. In the Reference Case these constraints begin to bind after fifteen years. The effects are apparent in Figure 21 (see following footnote). OECD extractors initially withhold oil in anticipation that the constraints will be binding on other producers. Once these constraints do begin to bind, OECD producers rapidly expand production.

Figure 21 also displays two other peculiarities in production projections of the Salant/ICF model. OECD extraction (and all other extraction) drops suddenly after 2002; production by OECD (and all non-LDC) surges suddenly after 2015. The drop occurs when price rises above backstop cost and backstop production suddenly is increased from nothing to full capacity of 6 MMBD. The sudden surge occurs after 2015 because the inexpensive LDC oil is projected to run out by that date.

Figure 4 shows that the irregularities in production are offsetting; no jumps are noted in total non-OPEC production. It is expected that the irregularities in production would not show such severe discontinuities if the ICF cost curves were replaced with assumed marginal costs which increase continuously with the production rate.

CRUDE OIL PRODUCTION (MMB/D)



OECD CRUDE OIL PRODUCTION

Figure 21

20 These conclusions about OECD production are illustrated in Figure 21 which appears on the page following this one.

21 Median values were taken independently for the four consumption estimates. Therefore the OECD, LDC, plus OPEC estimates may not add to the WOCA estimates. In particular for the years after 2000, WOCA estimates tend to be higher than the sum of the three components.

22 The model-based projections of Figure 5 differ significantly from the demand estimates in Figure 3. This difference occurs because Figure 3 is based upon constant real prices while the Figure 5 is based upon the higher market clearing prices. Thus the projections of the former figure can be expected to be higher than those of the latter, as they are.

23 This comparison requires estimating the oil demand reductions associated with the Low Economic Growth scenario, then dividing price changes by these estimated demand reductions to obtain the world oil price reduction per 1 MMBD of demand decrease. If world oil demand is 51 MMBD and the total consumption of energy is 120 MMBD oil equivalent, then a 10% reduction in the GNP for each nation can be expected to reduce world oil demand by 5.1 MMBD and world energy demand by 12 MMBD.

Results appear in Table 13 (page following this one). The first column shows oil price reductions per 1 MMBD import demand reduction for each model. The second two columns show price impacts of reduced economic growth. Numbers in the second column (labeled "all energy") are calculated by dividing by the total energy demand reduction, assumed to be equivalent to a 12 MMBD demand reduction in 1990 and 29.0 MMBD in 2000. Numbers in the third column (labeled "oil only") are calculated by dividing price changes by the oil demand reduction, assumed to be 5.1 MMBD in 1990 and 10.0 MMBD in 2000.

For the oil-only models, the price impacts per MMBD oil demand reduction obtained from GNP reductions are quite similar to those obtained by policies that directly reduce oil demand. The oil-only models are indicated by the asterick (*) in the column labeled "oil only". Only one model --OILTANK -- shows results differing by more than a factor of two.

For most models that include all energy, the price impacts per MMBD oil demand reduction exceed the price impacts per MMBD reduction in all energy use through GNP reductions and are smaller than the price impacts per MMBD oil demand reduction caused by GNP reductions. Models including all energy forms are indicated by astericks in the column labeled "all energy". For only one model -- ETA-MACRO -- is the price impact per MMBD of GNP-driven oil reduction strictly smaller than the impacts of direct demand reductions.

24 Exceptions to the expected direction of change are displayed by the Salant/ICF and the Kennedy models, in which reductions in the demand elasticity lead to consumption reductions in earlier years and increases in later years. This behavior is the result of the assumed intertemporal optimizing by oil producers, who reduce supply in early years, saving some oil for the future.

The high variability may stem from differences in procedures used by the various modelers to calibrate the demand functions. The closer is the historical price used in calibration to the projected price, the smaller will be the price impact of reducing the assumed elasticity. Thus, those models calibrated based on pre-1973 data can be expected to show much larger price differences than those calibrated using post-1973 price data. A part of the variability may also stem from differences in the point in the supply chain at which the price elasticities are measured. Some of the models may have implemented a constant price elasticity in the demand for crude oil, while

TABLE 13

**OIL PRICE REDUCTION PER 1 MMBD
IMPORT DEMAND REDUCTION (1981 Dollars)^a**

<u>Models</u>	<u>Oil Demand Reduction</u>	<u>Reduced Economic Growth</u>	
		<u>(All Energy)</u>	<u>(Oil Only)</u>
<u>1990</u>			
Gately	1.10	0.80 *	1.90
IEES/OMS	1.10	1.10 *	2.60
IPE	1.30	0.70	1.60 *
Salant/ICF	0.90	0.80	1.80 *
ETA-MACRO	2.00	0.40 *	0.90
WOIL	2.40	1.40 *	3.40
Kennedy/Nehring	1.00	0.70	1.70 *
OILTANK	1.00	1.40	3.40 *
Opeconomics	0.80	0.40 *	1.00
OILMAR	3.20	1.50	3.50 *
<u>2000</u>			
Gately	0.70	0.60 *	1.90
IPE	1.60	0.30	0.80 *
Salant/ICF	0.90	0.50	1.30 *
ETA-MACRO	1.60	0.60 *	1.60
WOIL	1.50	0.60 *	1.80
Kennedy/Nehring	0.60	0.30	0.90 *
OILTANK	1.70	0.90	2.80 *
Opeconomics	0.50	0.20 *	0.70
OILMAR	2.00	1.00	2.90 *

^a For Gately, OILTANK, Opeconomics, and OILMAR, all numbers displayed are five year averages of model results. For Kennedy/Nehring the Reduced Economic Growth numbers are five year averages. This averaging was needed because of the oscillatory nature of the results from these models.

others may have done so for the demand for refined oil, according to the logic of the particular model. These disparate procedures could, in a world where the markup on crude oil remains constant for all prices, cause divergences in the projections of oil prices. Finally, the result could in some way be related to the existence of an energy-GNP feedback mechanism in the model: those models with such a feedback mechanism show the four smallest price impacts.

25 Estimate by Exxon Corporation.

26 Disruption scenario results from three models--OPECONOMICS, IPE, and Salant/ICF--are not presented or discussed further here because: (1) results from OPECONOMICS for a 10 MMBD disruption were never submitted (although results for the previously requested 5 MMBD disruption showed almost no effects); (2) for IPE, the disruption was implemented so as to include anticipatory behavior by oil consumers, violating the study design, and (3) the Salant model includes a demand function in which the long-run and the short-run demand elasticities are identical and in these runs equal to -0.6. The group decided that the implementations of the disruption scenarios in these three systems did not adequately capture the intent of the scenario specifications.

27 In addition to the differences discussed, only one model -- Gately -- explicitly includes releases of oil stocks during the disruption. The release of 1 MMBD of oil stocks, assumed for these model runs, has a price impact equivalent to that of increasing the pre-disruption excess capacity by 1 MMBD.

28 The Oil Demand Reduction Scenario postulates a 5 MMBD reduction in OECD oil demand in 1985 when the disruption is assumed to occur. The calculating procedure is similar to that of Figure 8. See the complete report for the precise calculations.

29 More expensive projects might be justified on the basis of costs of oil imports which we did not consider in estimating the premium, such as the macroeconomic implications of disruption shocks.

30 The calculation described in the text -- equivalent to multiplying the price change per unit of import increase (\$0.90 to \$2.40 per barrel/MMBD) by the quantity imported (5.5 MMBD), to obtain or \$4.95 to \$13.20 per barrel -- is in fact slightly incorrect. An integration under the net import demand curve is required. Such a theoretically correct procedure would give a market power premium between \$5.18 and \$13.80 per barrel under our Reference case assumptions.

We can extend the logic of the example further. Suppose that one individual decided to import 0.5 million additional barrels of oil per day, thereby driving prices upward. The increased prices would cause all other users to decrease their demand for oil. Therefore, the actual import increase would be less than 0.5 MMBD. The new importer would have imposed "external costs" on all other users of oil equal to the price increase multiplied by their quantities of oil consumed. They face no additional net cost as they cut back on their use of oil, under the assumption they were initially optimizing. The market power premium is this external cost, the cost imposed on others, per unit of increased demand by the new importer. The market power premium is not measured by the external cost per unit of increased total consumption by all users. Thus, the denominator for the premium calculations is the change in the import demand function, not the actual change in imports after price adjustments have taken place.

31 Discount rates of 3 percent real have been used.

32 The total import premium is computed by taking the expected value of the benefits per unit of import reduction -- the sum of the per unit benefits in the disrupted cases and in the non-disrupted cases weighted by their respective probabilities. The security component as we have defined it is just the total premium minus the market power component.

33 The market power component is evaluated by comparisons of the Oil Demand Reduction Scenario to the Reference Scenario, and of the Oil Demand Reduction/Low Elasticity Scenario to the Low Elasticity Scenario. The security component is evaluated by comparing the Disruption/Oil Demand Reduction Scenario to the Disruption Scenario.

34 In calculating the security component we have used disruption cost reductions from Table 9 as approximations to the effects of a 10 MMBD, one-year interruption. This procedure can be expected to understate the component since it ignores the possibility that price increases occurring during the disruption may remain afterwards (remember the ratchet effect). Since the disruption occurs when the demand curve has been shifted by 5 MMBD, the component has been obtained by dividing the cost reductions in Table 9 by 1.825 billion barrels per year, the import reduction expressed on an annual basis and subtracting the market power component.

A more accurate estimate would be obtained if the numerator were a discounted sum of the cost reductions and the denominator were a discounted sum of demand reductions. If cost reductions and demand reductions are constant over time, then this procedure would be identical to that one used. Since this assumption does not hold precisely, inaccuracies are introduced by our procedure.

35 This implies a 40 percent probability of such a disruption occurring at least once in the next ten years.

36 In Energy Future: Report of the Energy Project at the Harvard Business School, 1979, New York, Random House.

37 In "Import Management and Oil Emergencies," Energy and Environmental Policy Center, John F. Kennedy School of Government, Harvard University, 1980.

38 In "The Energy Problem: Costs and Policy Options," Office of Oil Policy, U.S. Department of Energy, 1980.

39 This will occur if backstop capacity cannot grow rapidly enough to satisfy oil demand (net of conventional oil production) at the backstop cost.

40 In OILTANK price projections vary before 1996 because, unlike other models, OILTANK allows backstop production in the 1990-1995 interval.

41 The "1980 actuals" data in Table A5 were taken from the BP Statistical Review of the World Oil Industry, 1980, except for OPEC oil consumption, from International Energy Statistical Review, May 26, 1981, and price, from Weekly Petroleum Status Report, February 6, 1981.

Non-OPEC LDC consumption and production are residuals. Production includes natural gas liquids (NGL) in both the actuals and the model projections. Consumption excludes U.S. processing gains (0.6 MMBD). OPEC production includes crude oil only.

APPENDIX A
NUMERICAL INPUTS AND OUTPUTS

Tables A1 through A4 provide numerical assumptions defining the scenarios. Table A1 provides a schematic representation of the scenarios, describing them in terms of the key input variations. Table A2 shows oil demand reductions for those scenarios which examine such reductions. Table A3 presents assumed maximum production rates for backstop energy in the three cases. Finally, assumed growth rates of GNP appear in Table A4 for the Reference case and the Low Economic Growth case.

Tables A5 through A9 display quantity (and price) projections by the various models for the years 1980, 1990, 2000, 2010, and 2020. Oil production and consumption data are separately displayed for several regions: OECD, U.S., Europe, OPEC, non-OPEC LDC's, and WOCA total. Primary energy consumption and production estimates appear for OECD and WOCA totals. In addition, exports from OPEC and imports to the OECD are tabulated. Finally, the world price projections are presented.

Table A1
Scenario Descriptions[†]

Scenario	Demand Reductions	Long-Run Primary Energy Demand Elasticity	Economic Growth Rate	OPEC Production Capacity	Non-Conventional Energy Supply
1. Reference	none	Oil: -0.6 energy: -0.4	See Table A3	34 MMBD	\$60/bbl Limited Quantities (Appendix B)
2. Oil Demand Reduction	20 MMBD by 2020				
3. Low Elasticity		-0.375, -0.25			
4. Oil Demand Reduction/ Low Elasticity	20 MMBD by 2020	-0.375, -0.25			
5. Low Economic Growth			2/3 of Reference Rates		
6. Restricted Backstop					50% of Reference Limits
7. Disruption				24 MMBD from 1985 on	
8. Technological Breakthrough					\$40/bbl; Increased Limits
9. Disruption/ Low Elasticity		-0.375 -0.25		24 MMBD from 1985 on	
10. Optimistic	20 MMBD by 2020			Gradual Increase 40 MMBD in 1987	\$40/bbl Increased Limits
11. Oil Demand Reduction/ Disruption	20 MMBD by 2020			24 MMBD from 1985 on	
12. High Price					

[†] Blank boxes imply the reference case value is to be used. Reference case values do not override endogenously determined values.

Table A2
OIL DEMAND REDUCTION CASE: REDUCTIONS

Year	Demand Reduction (MMBD)
1980	0.0
1981	1.0
1985	5.0
1990	6.67
2000	10.0
2010	15.0
2020 and after	20.0

Table A3
BACKSTOP MAXIMUM PRODUCTION LEVELS

Year	Restricted Backstop	Reference	Technological Breakthrough
1995	0.0	0.0	0.0
1996	0.5	1.0	1.0
2000	2.5	5.0	5.0
2005	5.0	10.0	10.0
2010	10.0	20.0	20.0
2015	13.75	27.5	40.0
2020	17.5	35.0	80.0

Table A4
 ANNUAL GROWTH RATES OF GNP FOR CONSTANT WORLD OIL PRICES:
 REFERENCE AND LOW ECONOMIC GROWTH ASSUMPTIONS

	<u>1980-2000</u>		<u>Post 2000</u>	
	Reference	Low Economic Growth	Reference	Low Economic Growth
OECD				
U.S.	3.1%	2.07%	2.1%	1.40%
Canada	3.5%	2.33%	2.5%	1.67%
Asia-Oceania	4.1%	2.73%	3.1%	2.07%
Europe	2.6%	1.73%	1.6%	1.07%
OPEC	6.4%	4.27%	4.4%	2.93%
LDC's	5.1%	3.40%	3.1%	2.07%

Table A5
 WORLD OIL SUPPLY, DEMAND, AND PRICE
 REFERENCE CASE, 1980

	1980* Actuals	Gately	IEES- OMS	IPE	Salant	ETA/ MACRO	WOIL	Kennedy	OILTANK	OPEC- ONOMICS	OILMAR
Oil Production (MMBD)											
OECD Total	14.7		15.6	15.3	3.6	14.5		13.1	15.0	15.7	
U.S.	10.2		10.6	10.7	2.8		10.9	9.5	12.4		10.0
Europe	2.5		2.8	2.6	0.3				2.2		
OPEC Total	27.3	28.6	28.0	31.0	30.6		30.7	31.0	31.5	30.3	28.7
LDC (Non-OPEC)	5.8		5.9	5.7	6.4				5.3	5.2	
WOCA Total	47.9		50.1	52.1	40.6		51.4	47.7	51.8	51.2	48.5
Primary Energy Production (MMBOE)											
OECD Total						52.1					
WOCA Total		96.1					95.6			101.2	
Oil Consumption (MMBD)											
OECD Total	38.0		39.8	41.2	32.1	36.7	42.3	39.2	41.8	40.8	
U.S.	16.4		17.6	17.6	14.2		18.8	17.6	20.6		17.5
Europe	14.0		14.4	14.4	11.2				14.8		
OPEC Total	2.8	2.7	2.7	1.9	2.1		2.7		2.3	2.6	
LDC (Non-OPEC)	8.2		7.6	9.0	6.4		7.5		8.1	7.3	
WOCA Total	49.0		50.1	52.1	40.6		52.5		52.2	50.7	48.5
Primary Energy Consumption (MMBOE)											
OECD Total	76.3					74.3	77.9				
WOCA Total	95.5	97.9					95.6			101.2	
Oil Trade (MMBD)											
OECD Imports	23.1		24.3	25.4	28.5	22.2		26.1	27.6	25.6	
OPEC Exports	22.9		25.3	29.1	28.5		28.0	31.0	26.9	27.7	28.7
Price (1981 \$/b)											
WOCA	34.7	32.1	33.9	36.3	43.7	32.1	34.6	38.3	33.3	28.9	32.5

* See Footnote 41 for sources.

Table A6
WORLD OIL SUPPLY, DEMAND, AND PRICE
REFERENCE CASE, 1990

	Gately	IEES- OMS	IPE	Salant	ETA/ MACRO	WOIL	Kennedy	OILTANK	OPEC- ONOMICS	OILMAR
<u>Oil Production (MMBD)</u>										
OECD Total		15.6	16.3	10.1	13.2		10.1	12.9	17.2	
U.S.		9.8	9.5	5.5		8.7	7.9	9.5		9.0
Europe		3.5	4.4	2.2				3.0		
OPEC Total	30.4	28.4	22.4	32.0		29.6	31.0	29.6	27.1	34.0
LDC (Non-OPEC)		10.5	10.9	10.0				7.3	5.8	
WOCA Total		54.4	49.6	52.1		53.5	46.8	49.8	50.1	55.7
<u>Primary Energy Production (MMBDOE)</u>										
OECD Total					62.2					
WOCA Total	119.2					125.0			117.3	
<u>Oil Consumption (MMBD)</u>										
OECD Total		39.3	36.1	36.8	35.4	38.0	36.5	34.6	39.6	
U.S.		17.3	15.5	14.0		15.9	15.8	17.1		18.9
Europe		12.9	12.1	11.4				11.7		
OPEC Total	4.0	5.2	3.7	2.7		5.5		3.2	3.1	
LDC (Non-OPEC)		9.5	9.8	12.5		10.8		9.6	7.0	
WOCA Total		54.4	49.6	52.1		54.4		47.4	49.7	55.7
<u>Primary Energy Consumption (MMBDOE)</u>										
OECD Total					84.3	92.1				
WOCA Total	119.2					125.0			117.3	
<u>Oil Trade (MMBD)</u>										
OECD Imports		23.7	19.8	26.8	22.2		26.4	23.9	22.4	
OPEC Exports		23.2	18.7	29.3		24.1	31.0	26.4	23.6	34.0
<u>Price (1981\$/b)</u>										
WOCA	52.9	46.1	37.2	55.5	50.6	47.8	56.8	63.0	39.7	64.0

Table A7
 WORLD OIL SUPPLY, DEMAND, AND PRICE
 REFERENCE CASE, 2000

	Gately	IEES- OMS	IPE	Salant	ETA/ MACRO	WOIL	Kennedy	OILTANK	OPEC- ONOMICS	OILMAR
<u>Oil Production (MMBD)</u>										
OECD Total			10.5	18.5	10.2		13.2	11.8	17.2	
U.S.			5.1	6.9		8.3	7.6	8.7		7.0
Europe			2.8	4.5				2.7		
OPEC Total	31.3		27.7	33.9		28.8	31.0	28.7	30.6	31.5
LDC (Non-OPEC)			14.3	12.5				8.1	5.8	
WOCA Total			52.5	64.9		53.2	47.7	48.6	53.6	52.0
<u>Primary Energy Production (MMBDOE)</u>										
OECD Total					77.9					
WOCA Total	152.2					161.0			151.7	
<u>Oil Consumption (MMBD)</u>										
OECD Total			34.4	40.2	36.5	35.7	35.6	30.9	40.3	
U.S.			15.5	13.4		13.9	14.9	15.2		17.3
Europe			10.8	10.9				9.9		
OPEC Total	5.9		8.6	3.9		8.1		4.6	6.1	
LDC (Non-OPEC)			11.9	20.8		14.8		11.7	7.2	
WOCA Total			54.8	64.9		58.7		47.2	53.6	56.3
<u>Primary Energy Consumption (MMBDOE)</u>										
OECD Total					99.3	110.0				
WOCA Total	152.2					161.0			151.7	
<u>Oil Trade (MMBD)</u>										
OECD Imports			21.5	21.7	21.3		17.4	20.1	23.1	
OPEC Exports			19.1	30.0		20.7	31.0	24.1	24.5	31.6
<u>Price (1981 \$/b)</u>										
WOCA	71.7		54.6	71.3	80.2	69.6	77.5	92.1	41.5	86.8

Table A8
WORLD OIL SUPPLY, DEMAND, AND PRICE
REFERENCE CASE, 2010

	Gately	IEES- OMS	IPE	Salant	ETA/ MACRO	WOIL	Kennedy	OILTANK	OPEC- ONOMICS	OILMAR
<u>Oil Production (MMBD)</u>										
OECD Total				6.7	7.9		7.4	7.8		
U.S.				2.1		6.1	3.7	5.7		5.0
Europe				2.0				1.8		
OPEC Total	27.9			34.0		28.1		29.3		31.0
LDC (Non-OPEC)				12.5				7.0		
WOCA Total				53.3		50.0	38.3	44.1		49.5
<hr/>										
<u>Primary Energy Production (MMBDOE)</u>										
OECD Total					99.7					
WOCA Total	183.5					206.0				
<hr/>										
<u>Oil Consumption (MMBD)</u>										
OECD Total				39.2	41.7	35.8	35.2	28.5		
U.S.				11.6		13.8	14.5	14.0		18.7
Europe				9.4						
OPEC Total	8.8			5.1		10.6		6.1		
LDC (Non-OPEC)				29.0		19.2		13.0		
WOCA Total				73.3		65.5		47.6		66.9
<hr/>										
<u>Primary Energy Consumption (MMBDOE)</u>										
OECD Total					117.7	106.0				
WOCA Total	183.5					206.0				
<hr/>										
<u>Oil Trade (MMBD)</u>										
OECD Imports				32.9	18.0		8.6	18.8		
OPEC Exports				28.0		17.6	31.0	23.6		31.0
<hr/>										
<u>Price (1981\$/b)</u>										
WOCA	71.3			88.8	64.1	81.8	71.4	129.7		120.2

Table A9
WORLD OIL SUPPLY, DEMAND, AND PRICE
REFERENCE CASE, 2020

	Gately	IEES- OMS	IPE	Salant	ETA/ MACRO	WOIL	Kennedy	OILTANK	OPEC- ONOMICS	OILMAR
<u>Oil Production (MMBD)</u>										
OECD Total				11.3	6.1		2.7	4.4		
U.S.				4.7		2.9	1.6	3.1		3.0
Europe				4.0				1.1		
OPEC Total	26.1			34.0		26.2		27.4		31.9
LDC (Non-OPEC)				2.5				5.4		
WOCA Total				47.8		44.4	31.7	37.1		48.4
<hr/>										
<u>Primary Energy Production (MMBDOE)</u>										
OECD Total					124.7					
WOCA Total	222.5					262.0				
<hr/>										
<u>Oil Consumption (MMBD)</u>										
OECD Total				38.3	49.3	40.5	38.1	27.9		
U.S.				10.6		14.6	15.6	13.6		21.4
Europe				8.2				8.0		
OPEC Total	13.0			6.4		14.1		8.5		
LDC (Non-OPEC)				38.1		24.8		15.3		
WOCA Total				82.8		79.4		51.7		82.3
<hr/>										
<u>Primary Energy Consumption (MMBDOE)</u>										
OECD Total					140.2	167.0				
WOCA Total	222.5					262.0				
<hr/>										
<u>Oil Trade (MMBD)</u>										
OECD Imports				27.0	15.6		0.6	13.6		
OPEC Exports				27.6		12.1	31.0	20.7		31.9
<hr/>										
<u>Price (1981 \$/b)</u>										
WOCA	93.8			106.1	68.9	69.1	71.4	152.3		127.3

APPENDIX B
A BRIEF GLOSSARY OF ECONOMIC TERMS

Consumers' surplus: when prices of a commodity increase, consumers of that commodity are made worse off while decreasing prices make consumers better off. Consumers' surplus is a monetary measure of how much consumers are harmed or benefitted. In particular, the change in consumers' surplus is an approximation of the amount of income or wealth a consumer would be just willing to forego in order to be able to buy the commodity at the lower price. Alternatively it is an approximation to the amount of income or wealth a consumer would require to be indifferent between receiving the income (or wealth) and facing the price reduction.

Discounted Sum of costs or benefits: Same as Present value of costs or benefits.

Externalities: an indirect consequence that is not conventionally measured among the economic costs or benefits or an individual project or enterprise. The standard illustration of this idea is provided by smokestack emissions during the era prior to environmental controls.

Price elasticity of demand for energy: the percentage reduction in energy demands associated with a one percent increase in the price of energy relative to other commodities, with GNP and other factors that influence energy demands held constant.

Partial equilibrium: an approximation in which it is supposed that the energy sector has only a minor impact upon the long-run rate of GNP growth. By contrast, a general equilibrium analysis allows for the indirect impacts of the energy sector upon the GNP--hence requires more data inputs.

Present value of costs or benefits: a capital sum with an economic value equivalent today to a future stream of costs or benefits. Depends upon the discount rate employed to convert future costs and benefits to their present value. Whenever a high discount rate is employed, this means that distant future costs or benefits will have a low present value.

Real price: the price of a commodity denominated in dollars of constant value, such as 1979 dollars. The real price is calculated by deflating the nominal price by an index (e.g., the GNP implicit price deflator of the Consumer Price Index) which reflects the general inflation throughout the economy.

Primary Elasticity: The elasticity calculated with prices and quantities measured at the wellhead, minemouth or point of entry. Elasticities could also be delivered at the secondary level (electric utility busbar or the refinery gate) or at the retail level. The farther down in the supply chain elasticities are measured, the higher is the calculated elasticity.