OIL PRICE FORECASTING DURING THE 1980s: WHAT WENT WRONG?

EMF OP 34

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March 1994

(Revised)
(reprinted from *The Energy Journal*, June 1994)

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Oil Price Forecasting in the 1980s: What Went Wrong?*

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This paper reviews forecasts of oil prices over the 1980s that were made in 1980. It identifies the sources of errors due to such factors as exogenous GNP assumptions, resource supply conditions outside the cartel, and demand adjustments to price changes. Through 1986, the first two factors account for most of the difference between projected and actual prices. After 1986, misspecification of the demand adjustments becomes a particularly troublesome problem.

INTRODUCTION

Why did energy analysts completely miss projecting oil prices during the 1980s—a decade free of supply interruptions? In the aftermath of the 1979-80 disruption, many oil experts anticipated steadily rising real oil prices, whereas nominal oil prices fell.

In 1980, virtually all nonmodeling experts shared the view of inevitable increases in oil prices. In fact, their judgmental forecasts often called for more rapidly rising oil prices than many model-based forecasts during the 1980s.[1]

The Energy Journal, Vol. 15, No. 2.

* I would like to acknowledge members of the eleventh Energy Modeling Forum working group on international oil supplies and demands for their invaluable discussions of world oil modeling, and particularly Dermot Gately and Mark Rodekohr, who both have conducted retrospective analyses of oil forecasts. I have also benefitted from very useful comments and encouragement from Morris Adelman, Perry Beider, Michael C. Lynch, and two anonymous referees. The usual disclaimers apply.

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1. Unlike many judgmental forecasts at the time, the Energy Modeling Forum (1981) projections examined in detail here showed future oil prices to be relatively soft for most of the 1980s before rising towards the end of the decade.

It is difficult to reevaluate these judgmental forecasts, because the analysts are seldom explicit about their assumptions. A revisit to some model-based projections made at the time, however, helps to uncover several key factors that explain why analysts were misled.

Does this experience indicate poorly specified models about the behavior of oil suppliers and producers or incorrect assumptions about the oil resource base, economic growth, and other factors? This question is very important because the state-of-the-art in world oil modeling has not changed significantly over the decade. What are the implications of using these models for projecting oil market conditions during the 1990s?

This article examines this issue, beginning with a retrospective review of a previous set of oil projections made in 1980, as a part of the Energy Modeling Forum's study, *World Oil*. Further insights are developed by constructing a simple representative world oil model that corresponds closely to those that were used in the *World Oil* study. This model (referred to as the *World Oil* model) is then used to simulate market conditions using actual inputs rather than those used in the *World Oil* study.

The analysis reveals a two-part story. It confirms that through 1986 energy decisionmakers would have been better served by more accurate GDP projections (a model input), particularly those for the developing countries. A secondary source of error was the failure to anticipate the extent of the increase in the supply of oil outside OPEC, even though most *World Oil* modelers were projecting some increase in these supply regions.[2] After 1986, however, inadequacies in the demand response to price surface. By 1990, oil price backcasts based upon the correct economic growth inputs and supply conditions would have been no closer to actual prices than were the original *World Oil* projections.

THE EMF *WORLD OIL* STUDY

The Energy Modeling Forum (EMF) conducted a controlled comparison of ten existing world oil models in 1980-81.[3] As in previous EMF studies, the research was conducted by an ad hoc working group of more than 40 leading analysts and decisionmakers from government, industry, universities, and other research organizations. In the EMF process, the working group pursues the twin

2. The position of the supply curve(s) is usually based upon resource estimates and engineering constraints on the rate of development, and hence, can be considered as a model input in many cases.

3. Gately (1984) succinctly summarizes the EMF scenarios and results, as well as those by Daly, Griffin and Steele (1983) done approximately at the same time. The latter are of interest because they projected a lower range for oil prices and are discussed briefly later in the article.

goals of (1) improving the understanding of the capabilities and limitations of existing energy models and (2) using these models to develop and communicate useful information for energy planning and policy.[4]

The models in the study were developed to prepare long-run projections of oil prices, oil production, and oil consumption and to study changes in these variables under alternative scenarios. They incorporate the behavior of three distinct agents: oil consumers, oil producers outside the cartel, and oil producers within the cartel. Oil consumers respond to Gross Domestic Product (GDP),[5] energy-saving trends in technology or economic structure (if present), and oil prices. The response of oil producers outside the cartel is governed by assumptions about trends in resource depletion and technology in addition to oil prices. The cartel behavior is represented in one of two basic ways: (1) a profit-maximizing monopolist, or (2) an imperfect competitor that sets the price based upon the degree of market tightness.

The models can be separated into recursive simulation and optimization models. Recursive simulation models assume that producers and consumers act on information only about past and current events. The models are recursive because the utilization rate of the cartel's capacity in one year determines the price change in the following year. In the intertemporal optimization models, one or more decisionmaker is able to incorporate information about future events. Embodied with perfect foresight, these decisionmakers seek the single strategy for maximizing current and future benefits—for example, the cartel's future flow of profits.

For reasons that will become clear, this paper focuses mostly on the recursive simulation models. These models report prices and supply-demand balances annually and focus exclusively on world oil markets. They employ lag-adjusted demand and Non-OPEC supply curves to determine the residual demand for OPEC oil in any year. The cartel's productive capacity is generally exogenous, based upon modeler judgment of a combination of economic and political constraints. The cartel sets a price based upon last period's price and rate of utilization of its capacity. In this way, oil prices, production, and consumption are determined recursively; market conditions in one year influence those in the succeeding year. Alternative fuel prices and interfuel substitution are not explicitly represented but instead are implicitly incorporated through the own-price elasticity for oil. (This assumes that both the relationship between oil and other fuel prices and the potential for interfuel substitution will remain the

4. The EMF process and key findings from previous studies have been discussed extensively in several papers, e.g., see Huntington et al (1982).

5. Shifts in the economies' structures and their effect on oil use are seldom incorporated explicitly. Most models have a rudimentary macroeconomic feedback effect that reduces oil demand (through lower economic growth) when oil prices rise.

same as in the past.) Some key technical information about the form of the equations used in these models is contained in the appendix.

It is important to note that the projections are conditional forecasts that depend importantly upon several key assumptions, supplied by the EMF working group, on economic growth, OPEC capacity, and Non-OPEC resources. The reference scenario assumed that over the 1980-2000 period OPEC would not produce above 34 MMBD and that the OECD and developing countries' economies would grow by 3 and 5% per year, respectively. The study design also specified a long-run price elasticity of -0.6 at the crude oil level, equivalent at the time to -0.4 for aggregate energy at the wholesale level. The scenario assumed that 50% of the 1973 oil price shock was already assimilated in the oil demand levels by 1979. And finally, the study recommended Non-OPEC oil production paths based upon available geologic studies of the oil resource base.

1990 PROJECTIONS BY MODEL

Table 1 contains a summary of whether the projected consumption, production, and price levels in the reference scenario over- or underpredicted actual oil market conditions in 1990 and by how much. The table reports the error in each projection, as a percent of the actual 1990 level. Mean errors, together with separate mean errors for simulation and optimization models, are shown at the top of the table.[6] Below these estimates are individual model discrepancies from history reported in two sets: the seven recursive simulation models and the three optimization models.

As is widely known, the models badly overpredicted the actual 1990 real oil price. Mean errors of more than 200% indicate that actual prices were no more than one-third of projected prices for many models. In addition, as a group, the models did noticeably better in projecting the total quantity of oil consumed than the quantity of oil produced from Non-OPEC and OPEC regions.

These results imply three additional points about oil price forecasting in the 1980s. First, the projections of oil consumption sustainable at any price were too high. Projected total oil consumption almost matched actual consumption, even though the models were grossly overpredicting prices. Second, the projections of the oil production level from outside OPEC sustainable at any price were too low. Projected Non-OPEC production fell below the actual level, even though the models were grossly overpredicting prices. And third, an overly optimistic assessment of demand conditions combined with a pessimistic assessment of Non-OPEC supply conditions contributed to the overprediction of oil prices during this period.

6. Mean errors rather than mean squared errors or some similar measure are used because they reveal the direction of bias in projecting a variable, within a class of models.

Table 1. Errors in World Oil Projections, 1990 (Percent from Actual)

	Consumption			Production		Price
	WOCA	OECD	Non-OECD	OPEC	Non-OPEC	
Averages:						
Simulation	-2.1	-0.2	-11.8	15.6	-16.7	214
Optimization	-1.7	-3.6	-0.6	26.5	-36.8	240
All	-2.1	-1.5	-10.0	18.0	-21.7	222
Simulation Models:						
OMS	2.6	4.5	-1.9	14.1	-8.5	189
IPE	-6.4	-4.0	-12.3	-10.0	-4.2	133
OILTANK	-10.6	-8.0	-16.9	18.9	-28.9	294
Opeconomics	-6.2	5.3	-34.4	8.8	-19.0	149
WOIL	2.6	1.1	6.5	18.9	-15.8	199
OILMAR	5.1			36.5	-23.6	301
Gately				22.1		231
Optimization Models:						
Salant-ICF	-1.7	-2.1	-0.6	28.5	-29.2	248
Kennedy-Nehring	-2.9			24.5	-44.4	256
ETA-Macro		-5.9				217

The simulation models, as a group, tended to perform slightly better than the optimization models. The largest difference exists in the projections for Non-OPEC production, where the optimization models underestimated actual production by about 37% compared to 17% for the simulation models. This more pessimistic outlook on supply contributed directly to the slightly higher price forecasts of the optimization models, the average of which exceeds all but two of the simulation models.

Discrepancies between projected and actual production levels in the base year, 1980, account for a substantial amount of the lower 1990 projected production levels in the optimization models. These models compute long-run supply, demand, and price trends that are dynamically consistent in the sense that once these paths are determined, producers and consumers cannot increase their economic gains by shifting oil production and consumption either forward or backward in time. If oil markets are not positioned along this long-run path in the base year, serious calibration problems can result in such models. This characteristic makes this class of model more suitable for probing long-run economic trends associated with a depletable resource rather than for tracking intermediate conditions in which the oil market is moved away from such long-run paths. For this reason, we focus in the remainder of this paper on the projections from the simulation models in the *World Oil* study.[7]

No single model performs better than the others in all variables. The two U.S. Department of Energy models—OMS and WOIL—came very close to projecting the 1990 level of world oil consumption (excluding China and the formerly planned economies of USSR and Eastern Europe). On the supply side, all models underpredicted Non-OPEC production, with IPE (-4.2%) and OMS (-8.5%) registering the smallest errors. And finally, while all models badly overpredicted 1990 oil prices, IPE and Opeconomics estimated the lowest prices.

While all simulation models anticipated some increase in supplies outside OPEC, none anticipated the strong growth of almost 8 MMBD over the decade. As revealed in Table 2, IPE's estimate of about 6 MMBD and OMS's estimate of almost 4 MMBD came closest to the actual growth.

This comparison of projected with actual market conditions does not separate the effects of incorrect input assumptions from those of improperly specified model structures or parameters. In fact, small projection errors in this *World Oil* exercise do not necessarily imply a sound model structure, because key inputs such as economic growth rates and the Non-OPEC resource base were clearly incorrect. Given the large discrepancies between assumed and actual economic growth rates, any individual modeler should take little solace from demand and price projections that happened to be closer to actual 1990 levels than other projections.

SEPARATING MODEL INPUT FROM STRUCTURE ERRORS

Adopting the standard macroeconomic outlook at the time, the *World Oil* reference case was too optimistic about economic growth in both the developed and developing countries. Through 1985, the developed economies actually grew at 2.5% per annum rather than the 3.0% per annum that was assumed in *World Oil*, while the developing countries actually grew at 2.9% per annum rather than an assumed 5.5% per annum. In addition, the *World Oil* scenario design called for an income elasticity of oil demand equal to 1.3 for the

7. Moreover, today, the simulation models are much more widely used for oil price forecasting than are the optimization models. In a more recent Energy Modeling Forum study (1991) on this topic, nine of eleven models used recursive simulation.

Table 2. Projected Changes in Non-OPEC Oil Production, 1980-1990 (Million Barrels per Day)

Simulation Models:	
OMS	3.9
IPE	6.1
OILTANK	-0.1
Opeconomics	2.1
WOIL	3.2
OILMAR	1.9
Gately	NA
Average	2.9
Optimization Models:	
Salant-ICF	10.1
Kennedy-Nehring	-0.9
ETA-Macro	NA
Average	4.6
All Models Average	3.9
Actual	7.8

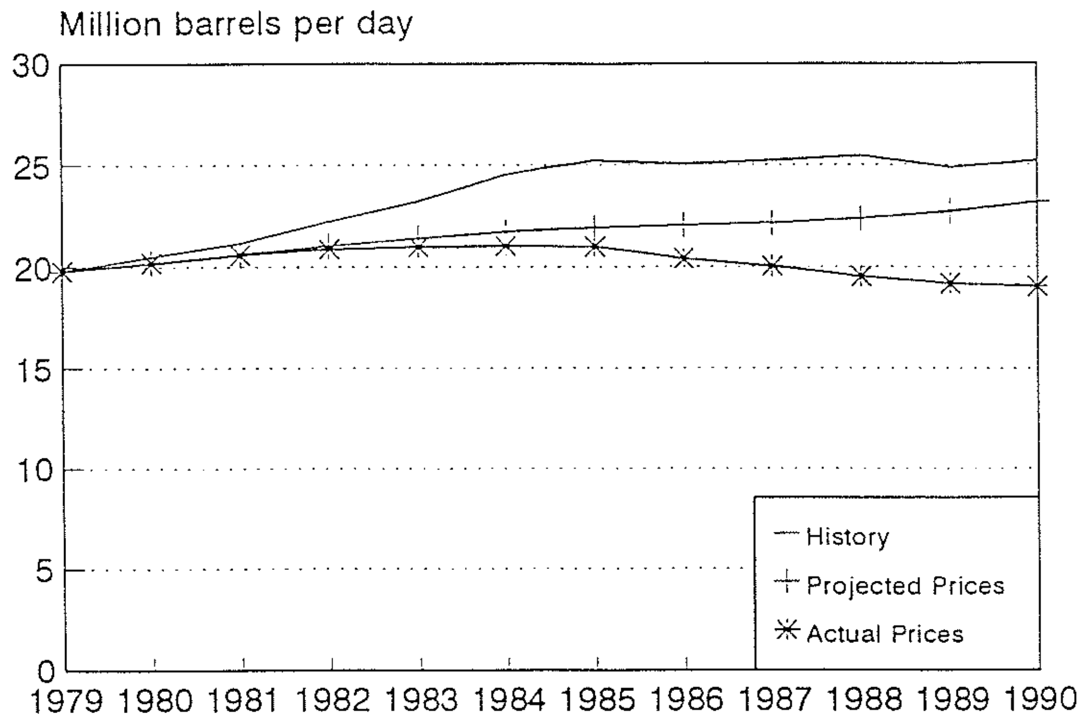
developing countries, which in hindsight appears considerably larger than what most analysts today believe is the response to income in these countries. Finally, the prevailing resource assessments for regions outside OPEC were too pessimistic, given the experiences of the 1980s.

It would have been useful to backcast the decade with the models as they existed in 1980, using actual values for GDP and the Non-OPEC resource base. Unfortunately, this was not possible because none of the models was available as it existed 10 years ago.[8] However, it is possible to construct a *World Oil* model, representative of the seven recursive simulation models, that replicates fairly well the responses of the actual models.[9] This model was used to backcast oil prices and quantities over the 1980s adjusting different assumptions and parameter values.

8. The EMF asks the individual modeler to run the different scenarios using commonly specified inputs. The model codes are not physically transferred to the EMF headquarters, because it would become prohibitively expensive for one organization to run ten different models.

9. The appendix describes how the model was calibrated.

Figure 1. Non-OPEC Production Backcasts with Stand-Alone Supply Equation

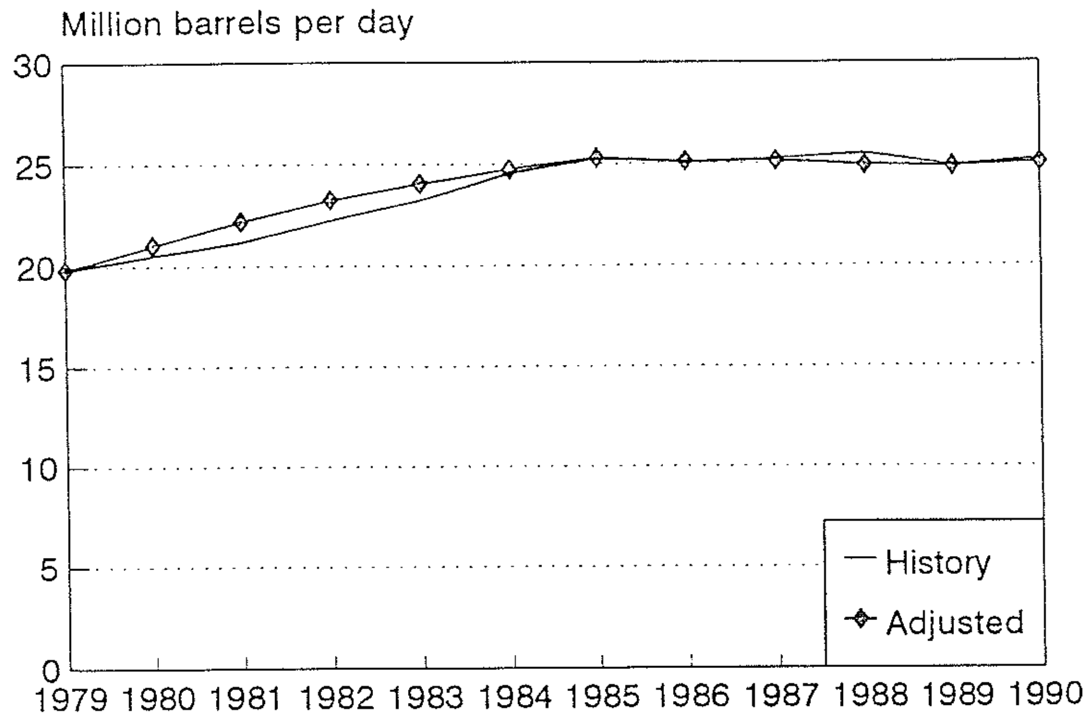


Stand-Alone Quantity Backcasts

As a useful first step, consider the backcasts when the supply and demand equations are isolated from the rest of the model. In this mode, oil prices are assumed exogenously rather than being determined endogenously by the interaction of relationships for demand, Non-OPEC supply, and OPEC pricing.

Figure 1 compares actual production outside OPEC and excluding China and the former Soviet Union with production backcasted with the stand-alone supply equation, based upon actual crude oil prices and study assumptions about nonprice factors. The use of actual prices effectively removes the model's OPEC pricing behavior and assumes that oil prices can be predicted exactly. Any remaining discrepancy from actual production reflects problems with the supply equation's specification.

Figure 2. Adjusted Non-OPEC Production Backcasts with Stand-Alone Supply Equation



Backcasted production with actual prices remains relatively stable throughout the decade and lies well below actual production. The projected gradual rise in production in the *World Oil* study is due largely to the higher projected oil prices, as indicated by the backcasts using the study's oil price path.

A relatively simple adjustment in the long-run supply curve's intercept can lead to backcasts that track actual production much more closely (Figure 2). The *World Oil* Non-OPEC supply curve is consistent with a long-run production of 24 million barrels per day (MMBD) at an equilibrium price of $35 per barrel (1982$). The new curve is formed by shifting the supply curve rightward, reaching the same long-run production but at an equilibrium price of $13 per barrel. The long-run price elasticity and adjustment lag have not been changed.

Figure 3. Market Economies Consumption Backcasts with Stand-Alone Demand Equations

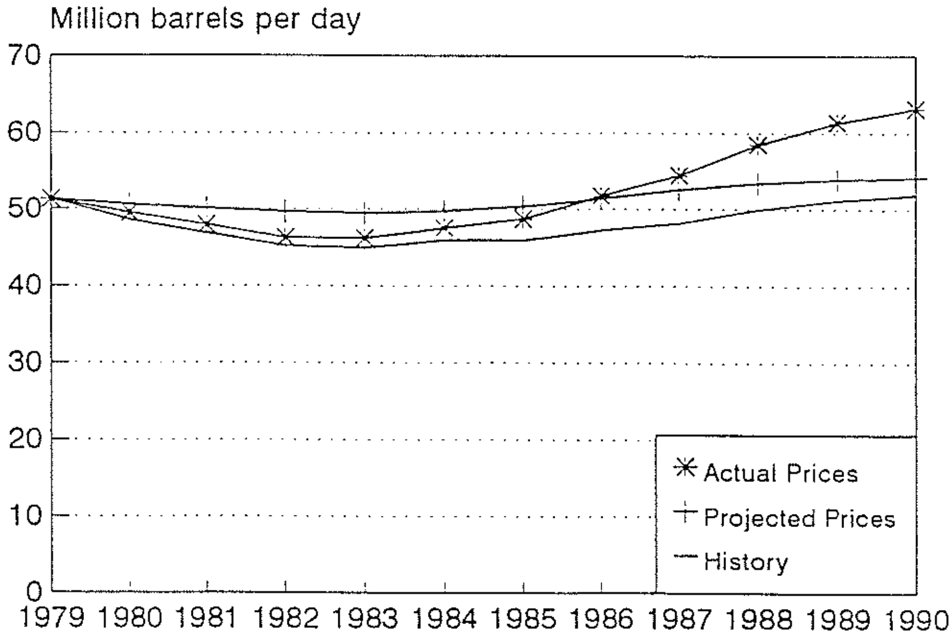
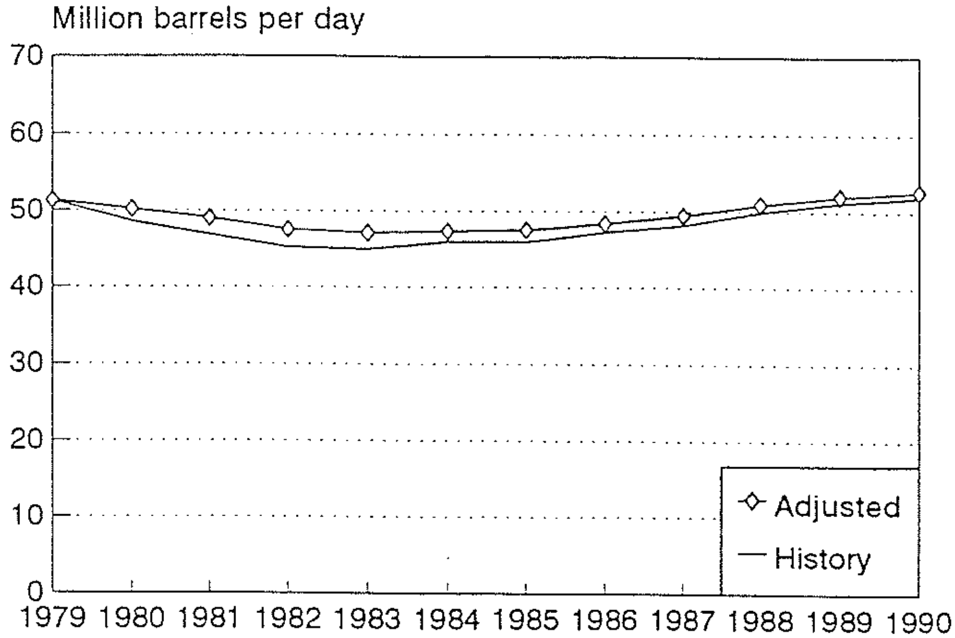


Figure 3 compares actual consumption (excluding China and the formerly planned economies of the Soviet Union and East Europe) with consumption backcasted with the stand-alone demand submodel, based upon actual crude oil prices and economic growth. Backcasted consumption exceeds actual consumption by a small amount through 1982, but this gap widens in 1983 and by a much greater amount after 1985. Actual crude oil prices began to fall in 1983 and collapsed in 1986. With this price path, the *World Oil* model projects rapid oil consumption growth beginning in the middle of the decade. The projected slow growth in consumption in the *World Oil* study results from the substantially higher projected oil prices, as indicated by the backcasts using the study's projected oil price path.

The lower oil price path observed over the decade did not induce the rapid oil consumption growth shown in the previous backcast based upon actual prices. Interestingly, many parameter adjustments do not improve these consumption backcasts, as reported in the appendix. Reducing the long-run price elasticity in half results in unrealistically high consumption backcasts, particularly early in the decade after the 1979-80 price shock.[10] Lengthening the demand adjustment period by allowing only 5% rather than 10% of the existing capital stock to respond to the current price does even worse.

10. A crude price elasticity of -0.6 is broadly consistent with surveys of a higher gasoline elasticity (Dahl, 1986, and Dahl and Sterner, 1991) and with crude oil elasticities used in many current world oil models (Huntington, 1991).

Figure 4. Adjusted Market Economies Consumption with Stand-Alone Demand Equations



Several adjustments do appear promising. The consumption backcasts improve when either the oil price path is tied to OECD end use rather than world crude oil prices or the income elasticity is cut by one half. The lower income elasticity would be appropriate if the presence of autonomous oil-saving trends during the 1980s was causing oil consumption and economic growth to decouple, as found by Hogan (1993). Backcasts based upon both OECD product prices and the lower income elasticity (Figure 4) track actual consumption reasonably closely. Shifts in parameter values within the 1980-90 period have not been considered here because they are difficult to analyze with the representative *World Oil* model. Gately (1993) and Dargay (1990) have argued that oil consumption responds less to price declines than to price increases, particularly when the falling prices are immediately preceded by sharply rising prices. Asymmetry in the demand response to price could reflect the unavailability of older, more energy-intensive vintages of equipment for purchase when prices fall or the expectation of recent price declines to be reversed over the long run. It is possible that this asymmetry could explain the observed consumption path over the decade as well as did the adjustments for end use prices and income elasticity.[11]

11. Both the slope and the intercept of the demand function must be changed to represent demand asymmetry. Thus, the demand function needs to be recalibrated midway through the analysis, introducing a high degree of arbitrariness. This issue is better addressed through econometric tests, which often support the asymmetry argument. However, see Hogan (1993), who prefers a specification using an autonomous oil-saving trend.

More reliable oil market projections depend upon much more than better representation of pricing decisions by the oil-producing cartel. Even if prices had been anticipated correctly, the above backcasts demonstrate serious problems with the equations for projecting consumption and Non-OPEC production that were available in 1980. These errors in projecting demand and Non-OPEC supply conditions can be expected to influence oil price projections in important ways. This issue can be addressed by considering backcasts generated from the model with OPEC's behavioral pricing rule restored.

Integrated Price Backcasts

The backcasting included six adjustments: (1) adjusting downward the income elasticity of oil demand for developing countries from 1.3 to 1.0, (2) using the actual GDP path for developing countries, (3) using the actual GDP path for the developed OECD economies, (4) calibrating the Non-OPEC supply curve to more optimistic conditions representative of actual history, (5) accounting correctly for the growth in oil exports from the Centrally Planned Economies (CPE), and (6) reducing the income elasticity for demand in both developed and developing countries from 1.0 to 0.5. An adjustment for OECD end use prices was not made because the representative model is not configured to easily incorporate different oil prices for producers and consumers. These changes were implemented cumulatively so that each backcast scenario reveals the incremental effect of the last factor that was added.

Incorrect macroeconomic assumptions adopted in the *World Oil* study dominate the price forecasting errors through 1986, when oil prices collapsed to about $14 per barrel ($16 in 1990$). In Table 3, projected 1986 oil prices fall from almost $50 to $30 (1990$/barrel) after adjusting for the effects of economic growth on oil demand (the first three factors). This represents more than half of the observed discrepancy between the projected *World Oil* and the actual price paths. Another one-fourth of the discrepancy is explained by adjusting for the more optimistic Non-OPEC supply conditions. Together, these two factors appear to account for most of the difference between the *World Oil* and actual price paths.[12] If adjustments are made for expanding CPE exports and a lower income elasticity of oil demand, the resulting backcasted price is virtually identical to the actual 1986 price.

Before rushing to resurrect the actual *World Oil* models, consider the same adjustments for the 1990 backcasted price. Table 4 indicates a totally different account for the relative importance of the various sources of errors.

12. These findings are broadly consistent with Gately's analysis (1986).

Table 3. Projected 1986 Oil Price Under Different Backcast Scenarios

	Oil Price		Percent
	Level	Change	Explained
World Oil	49.65		
LDC Y Elasticity	44.63	-5.01	14.9%
+LDC Growth	38.36	-11.29	33.5%
+OECD Growth	30.46	-19.18	57.0%
+NOPEC Supply	21.82	-27.83	82.6%
+CPE Exports	18.51	-31.13	92.4%
+Y Elasticity = 0.5	15.38	-34.27	101.8%
Actual	15.97	-33.68	100.0%

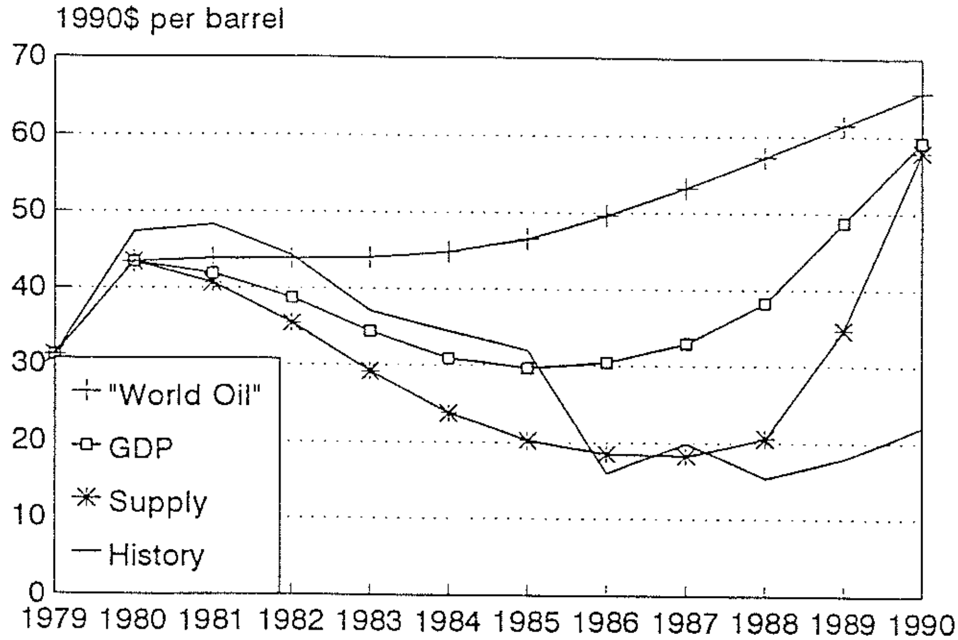
Note: Oil price is in 1990$/barrel

Table 4. Projected 1990 Oil Price Under Different Backcast Scenarios

	Oil Price		Percent
	Level	Change	Explained
World Oil	65.61		
LDC Y Elasticity	57.51	-8.10	18.6%
+LDC Growth	50.89	-14.72	33.8%
+OECD Growth	59.20	-6.40	14.7%
+NOPEC Supply	49.19	-16.41	37.7%
+CPE Exports	57.88	-7.72	17.7%
+Y Elasticity = 0.5	23.31	-42.29	97.1%
Actual	22.05	-43.56	100%

Note: Oil Price is in 1990$/barrel

Figure 5. Price Backcasts with Representative World Oil Model



The economic growth factors represented by the first three adjustments are decidedly less important. To a considerable extent, this result reflects the higher economic growth rate (3.4% p.a.) among OECD countries over the last half of the decade than the 3% that was assumed in *World Oil*. The adjustment raises the backcasted world oil price, offsetting to some extent the price reductions resulting from the other adjustments.

The other important difference is the much larger effect of reducing the income elasticity of demand by one half. The errors resulting from ignoring autonomous oil-saving measures accumulate over time. Adjusting for this misspecification shifts the demand curves inward by a greater amount each year.

The problems with the oil demand adjustments are emphasized in Figure 5, which provides a time profile of a few of the more important backcasted oil price paths. The line marked with pluses at the top of the figure represents the projected oil price using *World Oil* inputs, while the plain solid line at the bottom indicates the actual oil price path over the 1980s. The projected oil price path is quite representative of the *World Oil* results, with a slight dip in oil prices through the mid-1980s and a rapid spurt towards the end of the decade.[13]

The line marked "GDP" immediately below the *World Oil* price path represents the oil price path when the LDC income elasticity is set to 1.0 rather

13. See the appendix for a discussion of how this path compares with the actual *World Oil* estimates.

than 1.3 and when actual GDP growth rates are used for both OECD and LDCs. Together, these economic growth assumptions reveal an oil price already under considerable downward pressure by the early 1980s. When higher CPE exports and the more optimistic Non-OPEC supply conditions are also incorporated, the line marked "supply" reveals that actual prices were being held too high for the prevailing supply and demand forces in the early 1980s. Under these conditions, the *World Oil* model appears to suggest correctly that the world oil price should eventually fall in accordance with the soft market conditions.

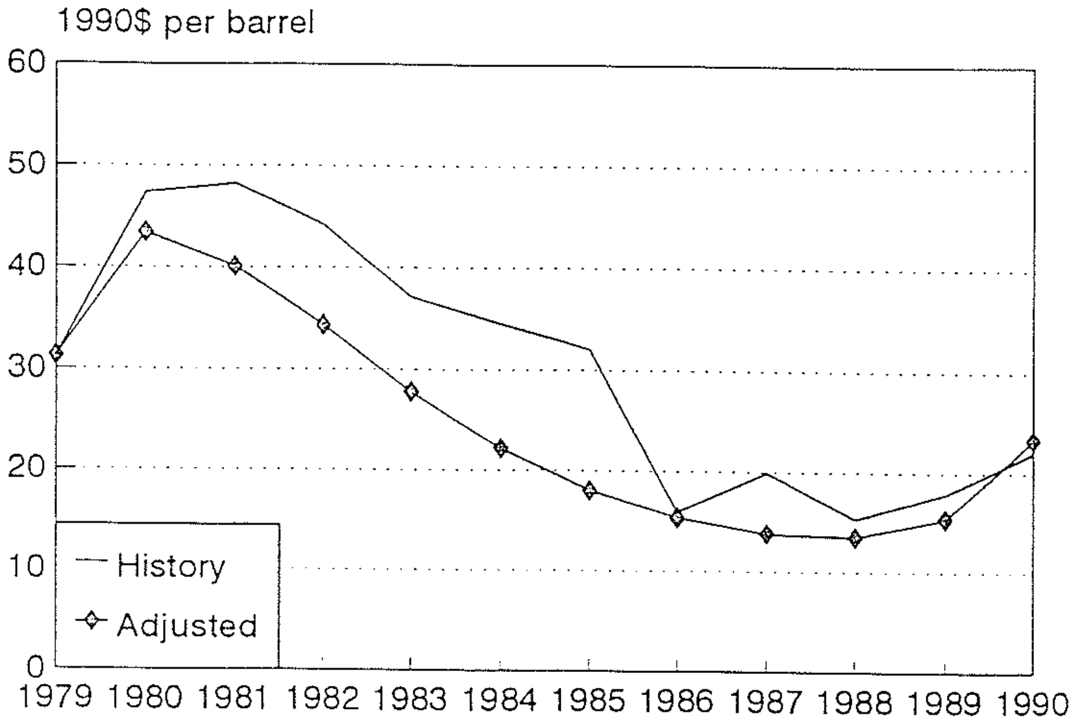
These explanations are insufficient for explaining the gap between projected and actual price paths after 1986. By 1990, the price backcasts incorporating both the GDP and supply adjustments are not much better than the original *World Oil* projections. Prices reverse their decline in these backcasts, because oil demand responds strongly to both lower prices and higher economic growth in the model. By 1990, this demand growth has very dramatic effects on the oil price, because OPEC is operating above its target capacity rate in the backcast simulations.[14]

The oil price backcasts are improved significantly by reducing the income elasticities of demand for developed and developing countries to 0.5. Figure 6 compares these backcasts for the 1980s with the actual price path. The incorporation of both more optimistic Non-OPEC supply conditions and an income elasticity of demand well below unity makes this adjusted backcast broadly consistent with the Daly, Griffin, and Steele (1983) projections also developed in the early 1980s. Their analysis, which was based upon an econometrically estimated income elasticity of 0.75, concluded that oil prices were likely to remain below their peak of the early-1980s.

As revealed in the figure, the backcasted oil price begins to rise sharply by 1990 and would continue to increase if extended beyond 1990 based upon actual GDP inputs. As a result, the backcasted price path departs from the actual price path after 1990, as OPEC production in the model begins to encounter the exogenous OPEC capacity constraint in the *World Oil* cases. Although arbitrary adjustments in OPEC's capacity would cause the backcasted price to decline along the actual price path since 1990, this result underscores the need for a credible model of Gulf producer behavior for understanding the oil market trends of the 1990s.

14. This result indicates that a full reconciliation of the 1980s must await a better understanding of OPEC decisionmaking, probably with a model not so closely wedded to the target capacity utilization approach. While it may be possible to discover a set of more appropriate parameters for adjusting the OPEC pricing rule, the criticism of the target capacity utilization approach by Powell (1990) and others raises serious questions about the utility of fine-tuning such pricing rules. Despite this limitation, the retrospective analysis here provides numerous useful lessons for modeling and thinking about oil markets in the future.

Figure 6. Price Backcasts with Adjusted Demand Equations in Representative World Oil Model



CONCLUSION

Projections of world oil market conditions made in the aftermath of the 1979-80 oil price shock grossly overpredicted actual prices during the 1980s but only mildly overpredicted actual consumption. The coexistence of these two findings emphasizes that the models failed to predict both the oil price level and the position of the world oil demand curve during the 1980s. Over the first half of the decade, economic growth and other factors did not shift world oil demand curves outward as rapidly as was anticipated in 1980. The macroeconomic inputs were most seriously in error for the developing countries, which were anticipated to grow more than twice as fast as they actually did over the decade.

The models also represented oil supplies outside the cartel too pessimistically. While the models projected some growth in Non-OPEC supplies, they missed the strength of this response. In combination with the inaccurate GDP assumptions, these supply conditions contributed to large overpredictions of the world oil price level.

World oil supply modeling remains problematic, as long as reliable information on regional drilling costs and country-specific taxation regimes remains unavailable. While the errors in projecting oil demand appear more dramatic in this analysis of the 1980s, the problems in projecting Non-OPEC supply may be longer term, given the lack of reliable data on key determinants of oil production.

There also exists evidence that the model's demand structure may be inappropriate, particularly after 1985, leading to a situation where no set of correct economic growth and resource base assumptions in these models would have produced a backcast of both price and quantity consistent with history. Demand did not respond as quickly or strongly to lower crude oil prices as would have been expected from the *World Oil* model. The oil price backcasts were significantly improved by the combination of allowing OECD product price trends to govern demand and reducing the income elasticities of demand to 0.5 in both developed and developing countries.

And finally, it should be noted that the model's concept of a cartel capacity constraint remains largely untested over the last decade, since actual demands for OPEC oil consistently fell well below OPEC's capacity. It remains speculative whether oil prices will swiftly rise once these levels are reached, or whether cartel producers will accommodate these trends with expanded capacity beyond the levels envisioned today.

The structure of world oil models has not changed much over the last decade, although individual supply and demand parameters (e.g., price and income elasticities) may well have.[15] On the surface, therefore, the past biases exhibited in previous projections should be of direct concern to policymakers and planners who rely upon these systems for price projections for the 1990s. There is a risk that the rising oil price path over the next several decades being projected by many world oil models may simply be an artifact of past biases—overpredicting demand and underpredicting supplies outside the cartel—carried further into the future.

15. Many current models project oil demand growing more slowly than economic growth with constant prices over the next two decades. This effect is incorporated either by an income elasticity below unity or by an exogenous improvement in energy efficiency operating over time. For a discussion of current oil models, and how they handle these demand issues, see Energy Modeling Forum (1991). See also Hogan (1989) for a useful study on the implications of using different demand parameters.

APPENDIX

Description and Calibration of the *World Oil* Model

The *World Oil* model was developed from parameters suggested in that study's scenario design (Energy Modeling Forum, 1982) and from a simple oil model (Braden, 1982) prepared by the EMF staff for that study. The *World Oil* model uses a Koyck distributed lag function for both demand and Non-OPEC supply. Changes in the oil-GDP ratio are governed by a long-run price elasticity of -0.6 with 10% of the demand adjusting each year (a lag parameter of 0.9). Income elasticities in both the short and long run are 1.0 and 1.3 for OECD and Non-OECD consumption, respectively. Supply parameters include a long-run price elasticity of 0.4 (inferred from interscenario comparisons reported by Beider (1982)) with the same 0.9 lag parameter.

Both the demand and Non-OPEC supply functions in the *World Oil* model were calibrated by choosing an intercept that allows the market to reach a steady state (where quantity tends to neither rise nor fall) at an assumed price and quantity. This intercept can be calculated for the supply function by setting $Q_t = Q_{t-1}$ and solving the Koyck-lag function,

$$Q_t = A\, P_t^{b(1-c)}\, Q_{t-1}^{\,c},$$

resulting in

$$A = P_t^{-b(1-c)}\, Q_t^{1-c},$$

where Q is quantity, P is price, A is the intercept, b is the long-run price elasticity, c is the lag parameter, and the subscript t denotes time.

Non-OPEC supplies were calibrated to a steady-state price of \$35 per barrel (1982\$) and a quantity of 24 MMBD, resulting in $A = 2.378$, as shown in the row labeled *World Oil* in Table A-1. When backcasted with oil prices projected in the study, these parameters result in projections of Non-OPEC production that follow closely those in the study. The second row shows the assumptions behind the adjusted Non-OPEC supply curve to more accurately reflect the actual historical experience of the 1980s.

Demand functions for both OECD and the LDCs were calibrated by replacing Q with D/Y^a in the above equation, where a is the income elasticity. The intercept then equals

$$A = P_t^{-b(1-c)} Q_t^{1-c} Y_t^{-a(1-c)}.$$

The computed intercepts assuming that 1973 and 1979 were steady-state years are shown in Table A-1. For the simulations, we assumed that the true steady-state conditions were somewhere between these two estimates. The 1979 figure was assigned a 60% weight and the 1973 figure a 40% weight, resulting in intercept values of 1.407 for OECD and 1.12 for the LDCs. In reducing the LDC income elasticity to 1.0 in the alternative cases, we recalculated the intercept to be consistent with the equation above.

Table A-1. Calibration of Supply and Demand Functions

	Price (1982$/B)	Quantity (MMMB)	GDP (1985$/B)	Intercept
Supply				
World Oil	35.00	24.0		2.378
Adjusted	13.00	24.0		2.474
OECD Demand				
1973	6.85	39.7	5824	1.359
1979	23.75	40.7	6825	1.445
World Oil	23.75	31.7	6825	1.407
LDC Demand				
1973	6.85	7.7	1355	1.074
1979	23.75	10.6	1830	1.149
World Oil	23.75	8.1	1830	1.120

The OPEC price reaction function was taken directly from the *World Oil* simple model. It appears to be quite representative of the actual functions used in the models. Its form is

$$(P_{t+1}/P_t) = G + h \ln(1-K_t),$$

where K is the rate of OPEC capacity utilization. Setting G = -0.421 and h = 0.222 yields a price reaction function that has prices neither rising nor falling at a target capacity utilization rate of 85%. At 90% capacity utilization, oil prices increase by 9%.

The *World Oil* model was backcasted using *World Oil* reference case inputs, including GDP assumptions. The resulting price path (Figure A-1) displayed an initial softness followed by steep rising in the latter half of the decade—trends that are broadly consistent with the mean reference case price path for the recursive simulation models and the price path for the IEES:OMS model. The latter is of note because the U.S. Department of Energy's Energy Information Administration continues to use the same structure (although possibly with different parameters).

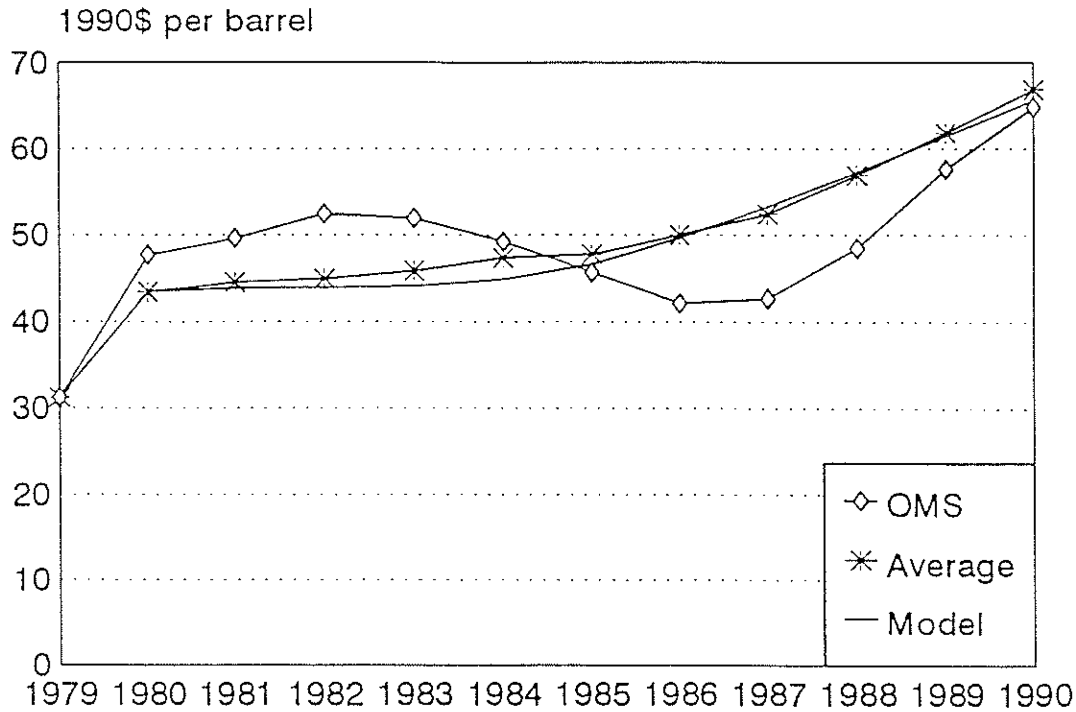
Table A-2 compares the oil consumption backcasts for the market economies based upon several adjustments to the oil demand equation for both developed and developing countries. These backcasts are based upon the stand-alone demand equations using actual prices. Adjustments for the response to price (either larger long-run elasticity or slower adjustment) produce inferior consumption backcasts. Those based upon either a lower income elasticity or OECD product prices are considerably better, with the combination of these adjustments providing the best backcast.

Table A-2. Alternative Market Economies Consumption Backcasts with Stand-Alone Demand Equations and Actual Prices and GDP (Thousands of barrels per day)

		Lower	Slower	Lower	OECD Prices:	
	Actual	Lower Price Response	Slower Price Response	Lower Income Response	Alone	with Lower Income Response
1979	51280	51280	51280	51280	51280	51280
1980	48600	50123	50785	49107	50588	50186
1981	46835	49114	50289	47196	50057	49015
1982	45195	47785	49333	45510	49623	47561
1983	44995	47835	49699	44972	49469	47135
1984	45940	49167	51338	45233	49695	47378
1985	45935	50245	52668	45554	50336	47524
1986	47250	52149	54832	47721	51386	48393
1987	48210	54047	57019	49320	52530	49473
1988	49950	56916	60244	51915	53405	50928
1989	51150	58926	62596	53671	53877	51975
1990	51920	60239	64222	54532	54160	52617

Sensitivity definitions:
Lower price response: Price elasticity declines from -0.6 to -0.3.
Slower price response: Percent of demand adjusting to price each year declines from 10% to 5%
Lower income response: Income elasticity declines from 1.0 to 0.5.
OECD: Crude oil price replaced by average OECD product price.

Figure A-1. Crude Oil Prices in "World Oil" Reference Case



The analysis is based upon historical data on oil production and consumption from British Petroleum (1992), on oil prices from Central Intelligence Agency (1985) prior to 1984 and International Monetary Fund (1992) after 1983, and on real GDP for OECD and LDC countries from International Monetary Fund (1992). The IMF indices for GDP were calibrated to 1981 GDP levels reported in Council of Economic Advisors (1983, p. 285). Nominal oil prices were deflated by the implicit U.S. GNP price deflator (Council of Economic Advisors, 1992). Real OECD end-use petroleum prices are available from International Energy Agency (1992).

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