AN EVALUATION OF BEHAVIORAL SIMULATION MODELS OF OPEC

Stephen G. Powell
The Amos Tuck School of Business Administration
Dartmouth College
Hanover, NH 03755

ABSTRACT

Behavioral simulation models of OPEC have typically been built on the assumption that OPEC price changes are determined by capacity utilization. We evaluate this model by examining its empirical and behavioral justifications, and by observing how it performs in a simple world oil market model. We also briefly explore and evaluate alternative behavioral rules for OPEC.

INTRODUCTION

The advent and continued existence of OPEC as an apparently effective resource cartel poses two problems. One is the problem of unstable prices and insecure supplies of crude oil faced by oil-consuming economies. The other, faced by energy analysts and modelers, is the problem of forecasting OPEC behavior and the overall behavior of world oil and energy markets. World oil modeling became a widespread concern after the Arab oil embargo of 1973-74, reaching a peak of activity in the late 1970's. Two comprehensive reviews of modeling activity in this field are Energy Modeling Forum 1982 and Griffin and Teece 1982.

World oil market models have been developed for a variety of purposes. One purpose is to test theories of market structure: does the world oil market behave in a manner consistent with a competitive market (see, for example, MacAvoy 1982), or a partially monopolized market (see Salant 1981; Marshalla and Nesbitt 1986). Another purpose is to evaluate government policies, such as import tariffs or petroleum reserves. Yet another purpose is to forecast future oil prices, supplies and demands.

Most world oil market models follow one of two paradigms. Natural resource economists have contributed a variety of *intertemporal optimization* models, while the Systems Dynamics community has contributed a set of *behavioral simulation* models. Each approach has its proponents and detractors. Attempts have been made to compare these two classes of models, notably in the Energy Modeling Forum's World Oil Study, but little is known about the relative forecasting accuracy of each class, or even the relative influence each has had on the policy debate.

While a comparative evaluation of the intertemporal optimization and behavioral simulation approaches to world oil market modeling would be of interest (see Powell 1990), the main focus of this paper is on the dominant behavioral simulation model, the so-called Target Capacity Utilization (TCU) Model. The TCU model rests on a simple behavioral rule that links OPEC's price (assumed to be a decision variable) with two other easily observable variables: OPEC production and OPEC capacity. Details differ among the models, but all versions are based on the idea that at high rates of capacity utilization OPEC will raise its price quickly, while at low rates of utilization it will lower its price slowly.

The purpose of this paper is to evaluate the TCU model and to explore the possibility of developing better behavioral simulation models. The paper is organized as follows. We first briefly discuss the strengths and weaknesses of the optimization and simulation approaches to oil market modeling. Then we describe the TCU model: how it has been justified and how it has been implemented. This leads us to a critique of the model for use in forecasting. Next we present a simple world oil market model which can serve as a testbed for various behavioral simulation models. We first test the TCU rule within this model and summarize the results. Then we describe a variety of behavioral simulation models in which revenue serves as the target in the place of capacity, and we test one of these models within the simple world oil market model. We conclude with a comparison of these two approaches to modeling OPEC.

MODELS OF OPEC

Most models of the world oil market are based on either the intertemporal optimization or behavioral simulation paradigm. We will characterize each of these approaches in this section.

Intertemporal optimization describes a model of decision making in which actors attempt to maximize some measure of wealth or utility over the foreseeable future. In natural resource modeling this approach is traditionally attributed to Hotelling 1931. Hotelling modeled the behavior of the owner of a depletable natural resource by assuming the owner would choose a production plan over time so as to maximize the present value of the net return from sale of the resource. This approach assumes perfect knowledge (of resource stocks, demand, and so on), perfect foresight (taking the entire future into account), and an optimizing motive. This class of model tends to produce smooth, often monotonic, time paths for prices and supplies.

The great strength of intertemporal optimization models is that they reflect economically rational behavior on the part of at least some actors in the market. To the extent that the actual decision maker's objectives are primarily economic, and their behavior is rational, this approach would seem to be well justified. There are, however, a number of serious drawbacks to the intertemporal optimization approach. First, the assumptions of perfect knowledge and foresight appear on their face to be unrealistic of human decision making. Second, these models are typically quite sensitive to assumptions about the price and availability of substitutes for oil, and on the discount rates of decision makers. Third, as a result of the optimization process the initial prices and quantities in these models are not necessarily current prices and quantities. Fourth, by focusing on intertemporal equilibria these models do not provide information on how the market will evolve in the short run from a position of disequilibrium. Finally, optimization models are generally unsuited to incorporating non-economic objectives on the part of actors in the market.

The major alternative to intertemporal optimization is the behavioral simulation approach. This approach is based on a radically different concept of the decision maker. Here decision makers are seen as highly constrained by limited information, limited computational ability, and limited decision making sophistication. Sterman gives the following hallmarks of this class of model:

> (i) A descriptive rather than normative representation of human decision making. Decision making behavior is portrayed in terms of the heuristics and routines used by the actors in the system rather than as the behavior which maximizes utility.
>
> (ii) The limitations of human cognitive capabilities are explicitly accounted for in modeling behavior.
>
> (iii) The availability and quality of information is explicitly treated including possible bias, misinterpretation, distortion, and delay.
>
> (iv) The physical and institutional structure of the system is explicit, including organizational design such as task and goal segmentation, the stock and flow networks that characterize the physical processes under study, and lags between action and response.
>
> (v) A disequilibrium treatment is adopted, focusing on the feedback processes which cause adjustments in the face of various external disturbances. (Sterman 1987, pp. 190-191)

From the perspective of world oil market modeling, the key aspects of this paradigm are the use of heuristics in modeling decision making, and the focus on disequilibrium rather than equilibrium behavior of the market as a whole. Decision makers in these models typically use simple rules of thumb based on observable market data, rather than sophisticated optimization methods. Such rules, of course, leave the decision maker open to achieving sub-optimal results; in fact sub-optimality is practically guaranteed. And behavioral simulation models typically predict that markets will oscillate from one point of disequilibrium to another, rather than achieving and maintaining an equilibrium. Proponents would see both of these properties of the approach not as weaknesses but as accurate reflections of reality.

The great attraction of the behavioral simulation paradigm is its (at least superficial) realism. Everyone recognizes the difficulty of making optimal decisions in practice, even in relatively simple situations. The problem confronting OPEC, which involves multiple parties, long time horizons, complex market dynamics, and great uncertainties, is so complex as to appear to overwhelm an explicit optimizing approach. However, the overriding weakness of the behavioral simulation approach is the lack of a theory or a body of empirical evidence that specifies which heuristic a given decision maker will use in a specific situation. The critics of this approach charge it with being *ad hoc*, meaning that (in contrast to the optimization approach) there is no overarching theory from which to derive behavioral rules for a specific situation.

For modeling the world oil market the behavioral simulation approach has several specific advantages. First, because these models are solved forward in time recursively they automatically begin with present prices and quantities. Second, because they are disequilibrium models, they offer a prediction of how today's disequilibrium will evolve in the future. Third, they provide scope for incorporating non-economic objectives for OPEC. In the following section we will describe the dominant model of OPEC within the behavioral simulation paradigm.

THE TARGET CAPACITY-UTILIZATION MODEL

The target capacity-utilization model is based on two assumptions: first, that OPEC is the residual supplier of oil in the world market, in the sense that it supplies the difference between world demand and non-OPEC supply; and second, it sets the price of oil based on the gap between its current capacity utilization and some target level of capacity utilization. The precise form of the relationship between price and capacity differs from model to model, but the most common specification relates the percentage change in price in the current year to the capacity utilization in the previous year. This relationship between price change and capacity utilization is typically nonlinear: above the target level of capacity utilization prices rise rapidly; below the target level prices fall slowly. This relationship is illustrated in Figure 1.

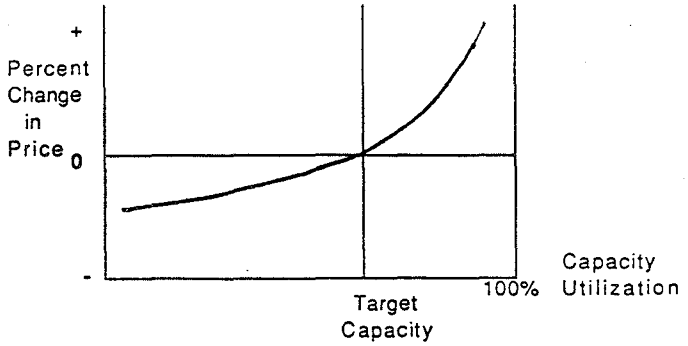

Figure 1. Target Capacity Utilization Model

The origins of this model are somewhat obscure, although the general idea of modeling OPEC rules of thumb was originated by Gately, Kyle, and Fischer 1977. Seven of the ten models included in the Energy Modeling Forum's 1982 study used some version of the TCU model. More recently one can recognize it in Gately 1983, EIA 1985, Sweeney and Boskin 1985, and Hubbard and Weiner 1986.

As we have stated, not all implementations of the TCU model use either the same driving variables or the same parameter values. All seven of the EMF models use capacity utilization lagged one year as one driving variable for current price changes. Other variables used in one or another model to modify the price change include: capacity utilization lagged two years, expected future capacity utilization, reserve-production ratios, costs, royalties, and minimum revenue targets. In Sweeney and Boskin 1985 quarterly (not annual) price change is related to excess capacity in millions of barrels per day (not to capacity utilization in percentage terms). Hubbard and Weiner relate the change in spot prices (not official OPEC prices) to capacity utilization.

Two justifications have been offered for the TCU model, one empirical and one behavioral. The empirical justification rests on the observation that oil prices since 1973 have tended to rise sharply following unexpected disruptions, and to decline slowly for a number of years thereafter. This has been termed the "price-ratchet phenomenon". It has often been asserted that this pattern is consistent with the TCU model of OPEC (see, for example, Hogan and Leiby 1985 III-6). An unexpected loss of capacity (for example) will drive capacity utilization above the target level and lead to large price increases. As the higher prices slowly work there way through the market, demand falls, non-OPEC supply increases and OPEC capacity utilization will fall. This leads to the observed pattern of slowly declining prices. The empirical evidence behind these observations will be examined later in this section.

Gately has offered the most cogent rationale for why this approach is a plausible model of OPEC behavior:

> This is intended as a positive description of likely OPEC behavior, not a normative description of how OPEC ought to behave. It represents our view of OPEC as a loosely disciplined cartel, groping toward a "good" price-path, not knowing the true parameter values underlying the market (such as elasticities of demand and supply, in the short and long run). It should be noted that "target" refers to the target of the *instrument*. It should not imply that capacity-utilization is itself a goal. The goal is OPEC's revenue and welfare over time. But, given the uncertainty about the true nature of the market and the difficulties of "fine-tuning" price, OPEC's welfare is best served by aiming at a "target" capacity-utilization. (Gately 1982, pp. 354-356)

Gately's statement should be compared to the five desiderata given by Sterman above for behavioral simulation models. In particular, it stresses groping behavior in an uncertain world. But it also admits that OPEC's ultimate objective must be welfare maximization. What is unexplained is why OPEC's interests are best served by focusing on capacity utilization as a target (as opposed to, say, revenue itself), or why the particular behavioral rule represented by the TCU model is best. In a later retrospective on OPEC and OPEC modeling, Gately 1984 discusses the TCU model at some length. In addressing the criticism that such models are *ad hoc*, he focuses on the three key ingredients of the TCU rule: the level of capacity, the target level of capacity utilization (at which price remains constant), and the shape of the price change-capacity utilization relationship.

As for the level of capacity, he notes that in almost all models capacity itself is exogenous. He admits that the level of capacity will affect longer-term results, but claims it will have little effect on the first few years of a forecast. Changes in the second and third factors will affect the timing of price changes by a few years, but will have little effect on the general shape of the price path over time or on the ultimate level of prices. No direct evidence is cited for these generalizations, and it would appear from the earlier work (Gately, Kyle, and Fischer 1977) that, at least for the particular TCU rule used there, changes in parameters do have a significant effect on price paths.

This defense of the TCU rule is interesting for a number of reasons. First, it highlights the fact that capacity itself is typically exogenous in these models. Yet the capacity decision is a central one for OPEC, especially over the long run. Griffin has commented on this issue as follows:

> ". . . economic modeling approaches that arbitrarily set OPEC capacity are begging the question. Capacity expansions must be endogenized, and once they are, the results are likely to be quite sensitive to the factors determining capacity expansions." (in Gately 1986, p. 282)

Of course, Gately's claim was that capacity had little effect in the short run, so if one's focus was on short-term forecasting, this critique may have less force. On the other hand, changes in the target level or the shape of the TCU curve will (Gately claims) only influence the details of the results, not the long-term values or the general shape. So if one's interest were in long-run forecasting, perhaps capacity itself matters but not the details of the TCU relationship.

All this points up the fact that one's evaluation of this model depends on one's purposes. Certainly in the long-run capacity is endogenous for OPEC, and should ideally be modeled as such. If one's interest is in the short-run, a fixed capacity level is more plausible. But it remains to be proven that short-run results really are insensitive to the parameters of the TCU curve.

Finally, this entire defense, which focuses on the sensitivity or insensitivity of model results to specification of the TCU rule, misses the point of the charge of *ad hoc-ery*. From the viewpoint of someone steeped in the tradition of intertemporal optimization, the very formulation of the TCU rule is suspect because it is not explicitly derived from an optimization model. And, of course, it is no defense to point out that existing optimization models have not performed well or make implausible assumptions about the knowledge or computational abilities of OPEC decision makers. The possibility always exists that a better optimization model, especially one that took these practical constraints into account, could be built.

We turn now to examine the claim that the TCU model is consistent with the historical behavior of the world oil market, at least since the rise of an effective OPEC in 1973. The historical evidence suggests that OPEC has been able to ratchet prices up during periods of market disruption, and to prevent rapid declines in prices thereafter. The Energy Information Agency has formalized this observation in the form of a relationship between the annual percentage change in price and capacity utilization. Figure 2 reproduces a graph from the EIA's Annual Energy Outlook for 1984 that shows the nonlinear relationship between these two variables over the period from 1975 to 1984. The implications of the figure are clear: over the ten years covered, high rates of capacity utilization have been associated with large price increases, and low rates with small declines in price.

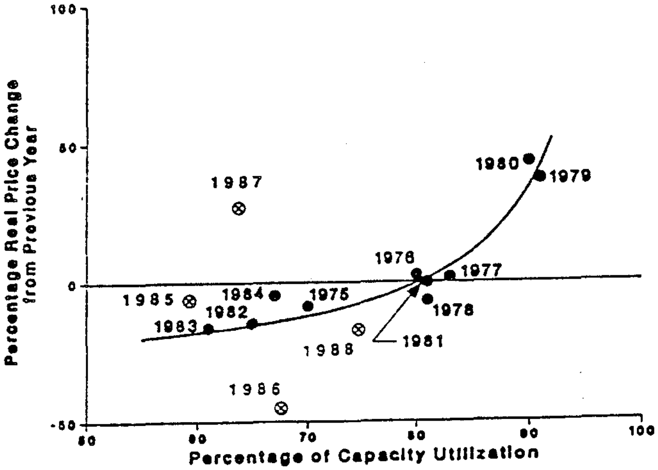

Figure 2. OPEC Pricing Behavior

An examination of the EIA's figure and the data behind it suggest some skepticism about the strength of the price-capacity relationship. First, note that there are only two years with capacity utilization significantly above 80%: in both 1979 and 1980 prices rose rapidly in years with high rates of capacity utilization. Four of the years are characterized by essentially no change in prices with capacity utilization around 80%. The lower tail of the curve is traced out by the remaining four years, when prices fell at low levels of utilization. Without engaging in elaborate statistical tests it is clear that these ten years provide very few data points to delineate a strong relationship. A shift in any one of the observations, particularly those at the upper end of the curve, could dramatically alter the relationship. While it is difficult to imagine a negative relationship between prices and capacity, the particular nonlinear relationship posited by the EIA does not appear to be convincingly established by this evidence.

History itself has provided another test of the relationship between prices and capacity. In Figure 2 we also plot the price-capacity data for the years 1985 through 1988 on the EIA's curve. Clearly, recent events do not appear to have treated the EIA model well. The observations for 1985 and 1988 lie reasonably close to the curve, but the years 1986 and 1987 fall well off the curve. In 1985, despite very low levels of capacity utilization, prices failed to fall. Then in 1986 prices fell an unprecedented 47%. In 1987 proces rebounded, only to fall again in 1988. All of these changes took place at historically low levels of capacity utilization

Hogan and Leiby 1985 raise two additional questions about the goodness of fit of the historical data to a hypothetical price-capacity curve. Upon investigating how OPEC capacity is defined and measured, they found a number of definitions in use and a number of different data series produced by reputable agencies and publications. They found that estimates of OPEC's maximum sustainable capacity in a given year differed by as much as 7 MMBD. And they observed that the relationship between percentage price changes and capacity utilization was closest for the EIA's own data on capacity. The second point raised by Hogan and Leiby was that most analyses of oil market trends focus on prices in U.S. dollars. However, the true price of oil to a particular country is the amount of consumption goods that must be foregone to purchase oil. This price will clearly differ between countries because of differences in exchange rates and purchasing power. Hogan and Leiby calculate that the $1.50 drop in U.S. refiner's acquisition cost observed in 1984, for example, corresponds to a $1.00 *increase* in the effective price paid by other importers. They also observed differences between countries of $5 to $10 in effective prices. This suggests that how one measures prices could make a great deal of difference to how one understands OPEC behavior.

In summary, we have examined the theoretical and empirical justifications for the TCU model. We have seen that the theoretical justification relies on the claim that OPEC's problem is so complex that only a simple behavioral rule focusing on maintaining capacity utilization near a target level is feasible. We also examined the empirical evidence for the TCU relationship and found a number of reasons for skepticism. In the next section we will examine the preformance of the rule within a simple world oil market model.

A SIMPLE SIMULATION MODEL OF OPEC

Our model (implemented in STELLA, Richmond 1987) is designed to be only as complex as is needed to illustrate and test the behavior of the TCU model. Accordingly, we include three highly aggregated sectors: world demand, non-OPEC supply, and OPEC supply. World demand is assumed to respond to the price of oil with an adjustment lag. The long-run elasticity of demand is -.6, with the adjustment lag set so that the complete adjustment to a price change takes roughly 12 years. Non-OPEC supply also responds to price with a lag. The long-run supply elasticity is .2, and the full adjustment takes 12 years. These parameters were selected as representative of the results of many studies of world oil supply and demand (see, Energy Modeling Forum 1982, p. 102).

We close the model by specifying OPEC's pricing rule. In the spirit of the TCU paradigm, we assume that OPEC acts as the residual supplier in the market, supplying world demand less non-OPEC output, at a price it chooses based on its capacity utilization. The particular pricing rule we adopt is

Annual Percent Change in Price = -45 + 9*(1/(1-Capacity Utilization)).

This function follows the EIA TCU rule closely: at 80% utilization price is held constant; at 50% utilization price drops 27%; at 90% utilization price increases 45%; and as capacity utilization rises toward 100% the price change increases without bound.

In the following simulations the oil market is assumed to start in equilibrium, with world demand at 50 MMBD, non-OPEC supply at 30 MMBD, and OPEC producing 20 MMBD and at its target level of capacity utilization (80%). Prices are initially $20/BL. As a base case we study the model's response to a capacity increase of 10 MMBD. Figure 3 shows that the response of OPEC to increased capacity is to lower prices (since capacity utilization has fallen below 80%). This generates an increase in demand and a decrease in non-OPEC supply. OPEC output expands to fill the gap, and OPEC capacity utilization increases back toward the target level. Prices drop for several successive years, but eventually the changes in demand and non-OPEC supply caused by OPEC's price changes bring capacity utilization back up above the target level. Prices then have to increase in order to bring capacity utilization back down. It is an inherent property of the TCU pricing rule that prices (and therefore all other variables) will oscillate around the new target level (which is 28 MMBD in this case). Figure 3 shows how, after the increase in capacity, production initially increases to close the gap. As the price response rule tries to catch up to the changes in demand and supply it generates a long period of slowly dampening oscillations in production. Figure 3 also shows the effect of this behavior on OPEC revenues. As we would expect, revenues also cycle, dropping slightly in the immediate aftermath of the increase in capacity, and increasing by almost 50% over the base level just a few years later. The TCU model does restore the market to an equilibrium eventually, although it takes many years to fully dampen the cycles in revenues. This equilibrium is characterized by OPEC production of 28 MMBD at a price around $16, for revenues of $450 Million per day.

The stability of any model when perturbed by unanticipated shocks is clearly a desirable feature. We see from the base case that the TCU model is stable in this situation, but it cannot insulate OPEC from wide swings in revenue. Another drawback is that the equilibrium it seeks does not maximize revenues. It is straightforward to calculate the price that maximizes OPEC's current revenue (without discounting), using the long-run demand and non-OPEC supply curves. For this case the revenue-maximizing price is $9.5 per barrel, which generates revenues of $497 Million per day, ten percent higher than the model equilibrium. This ten percent revenue loss is a rough measure of the economic price OPEC pays by following this rule-of-thumb pricing strategy. Another rough measure is the difference between the present value of revenues under the TCU pricing rule and the present value if prices were held at their long-run equilibrium. This difference is $180 Billion, or 14% of the TCU-determined present value.

We now turn to testing the response of the TCU model to an exogenous shift in the long-run demand curve. In Figure 4 we show the model's behavior with a long-run demand curve that shifts out at 6 percent a year. Figure 4 shows that demand and

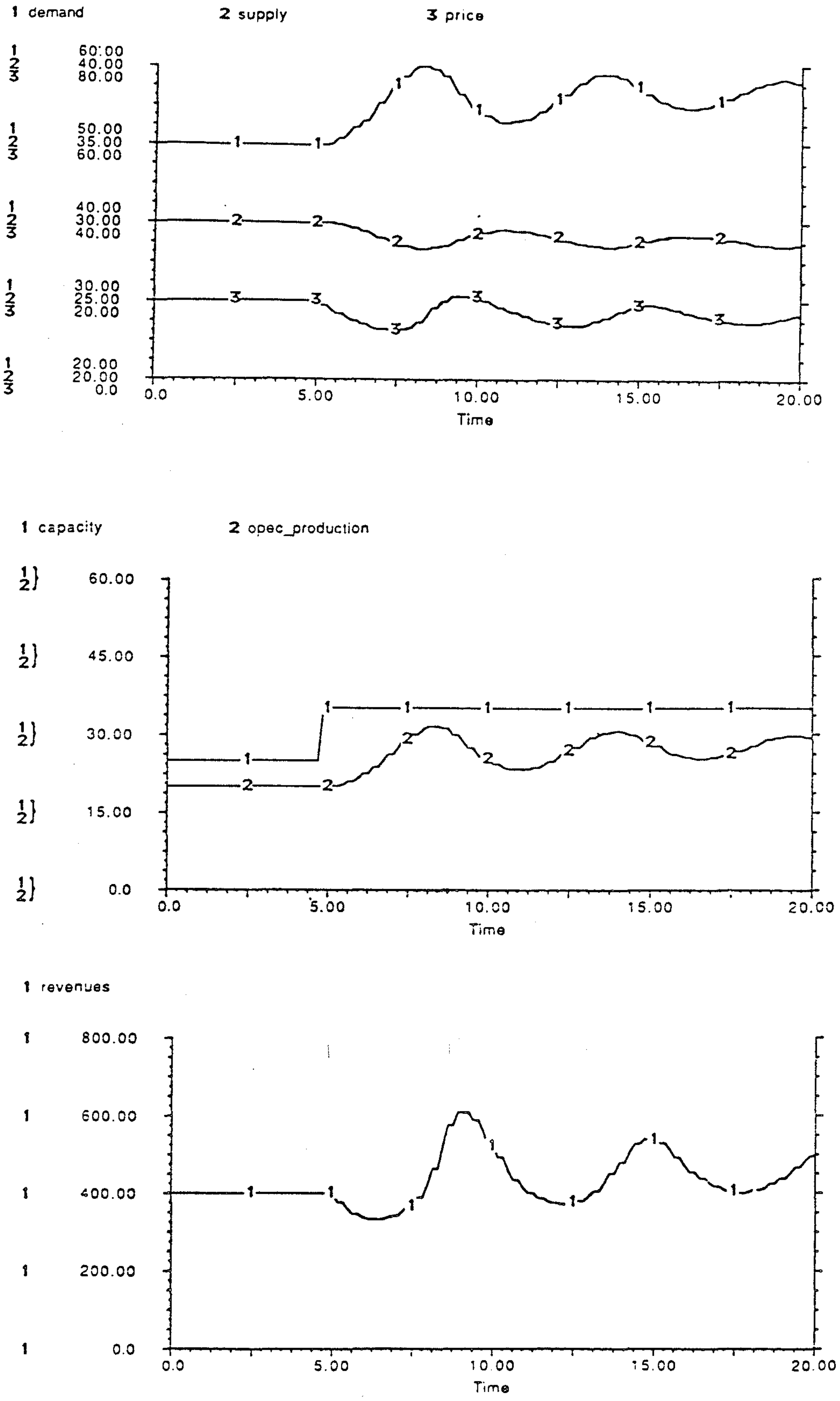

Figure 3. Model Response to 10 MMBD Increase in Capacity

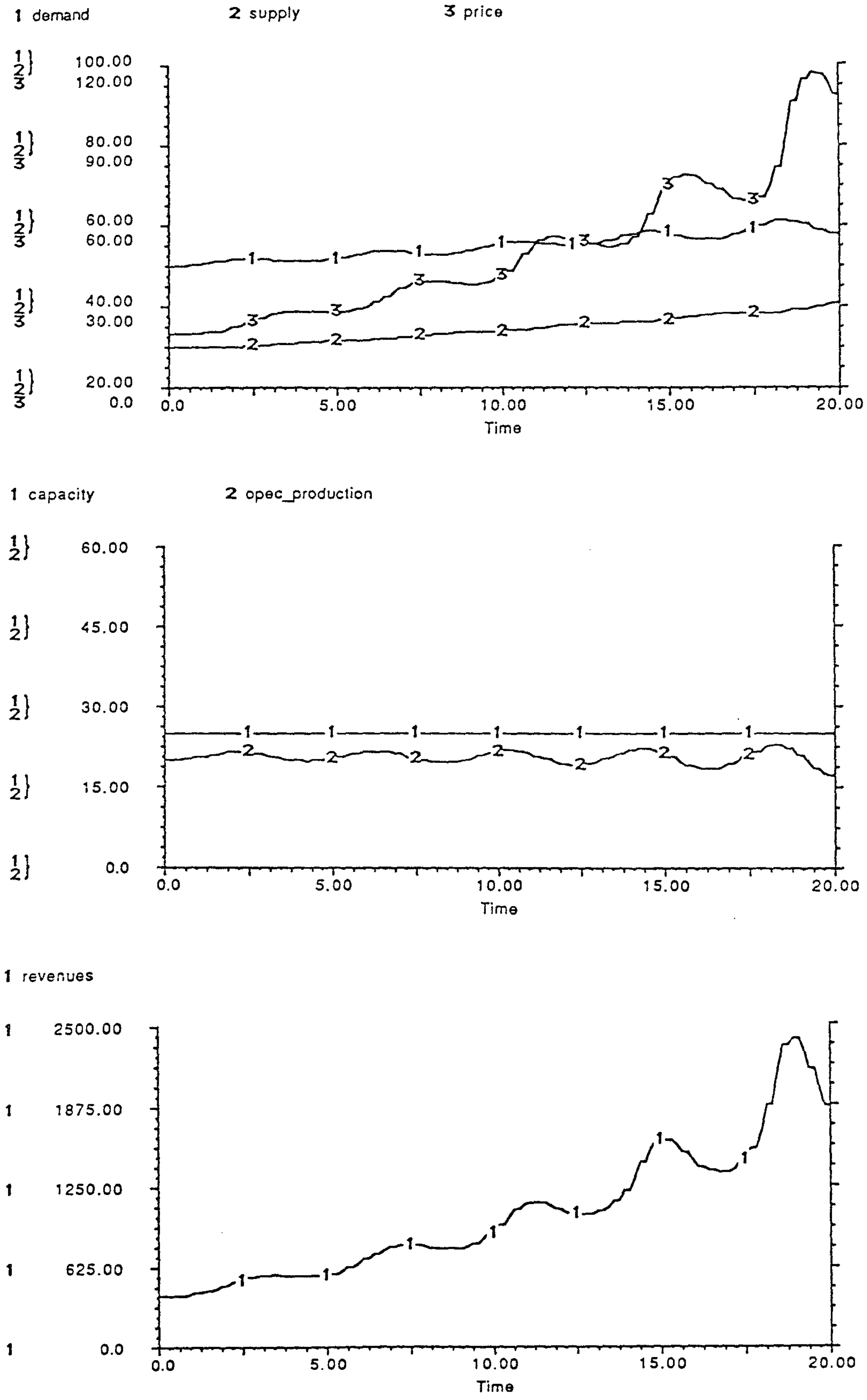

Figure 4. Model Response to Six Percent Demand Growth

non-OPEC supply increase gradually with slight cycling over the simulation period. But prices show undamped oscillations, reaching a level five times above the initial level after twenty years. The TCU model with a fixed level of capacity must strive to keep OPEC output near 80% of capacity. In the face of the rise in demand, OPEC must raise price constantly to force down the quantity of oil actually demanded. What is especially striking is the oscillating price pattern, and the fact that the amplitude of the oscillations increases over time. We see from this case that the TCU rule is susceptible to instability, even in situations where the underlying market forces are changing in a predictable manner.

The cyclic behavior of the TCU model can be viewed in another, more revealing manner. Instead of plotting demand, supply and price over time as we have, we can plot the percentage change in price against capacity utilization. This is the relationship on which this entire class of models is built (see Figure 1). This allows us to compare the actual behavior of the model to the relationship that defines OPEC's pricing rule.

In Figure 5 we plot annual percentage price changes against capacity utilization in the preceding year for the base case. One can immediately see that most of the data points lie near a convex curve that passes through the 80% target level. This would appear to be a confirmation of the EIA model, as supported by the data in Figure 1. On closer examination, however, one sees that successive observations follow each other in a generally predictable pattern. By following the successively numbered points, one can see that the model moves back and forth from the lower left quadrant to the upper right quadrant, usually with a period of 5-6 years. This is the cycling phenomenon we observed earlier, seen in a different light. These observations suggest that one should ask not simply whether the data lie on an upward sloping curve, but whether successive observations follow each other in the cyclic pattern observed in these graphs. A casual glance at oil prices since 1973 will suggest that there is little evidence the real oil market has shown the type of cycling observed in our implementation of the TCU model. Rather, the real market has shown quite strong hysteresis; that is, a tendency to stay put rather than to return to an equilibrium after a shock. The TCU model does not appear to produce this type of behavior.

Briefly summarizing these experiments, we have seen that the TCU rule has the ability to return the market to an equilibrium when disturbed, but this equilibrium may not represent an especially attractive one for OPEC. Moreover, the approach to that equilibrium will generally be cyclical. We also observed that in certain market environments and for some specifications of the TCU rule the model is not stable. Finally, we noted that the model generally exhibits a tendency to cycle around the target capacity level, a behavioral mode not readily apparent in the historical record.

TARGET REVENUE MODELS

We have seen that the TCU model is unstable for a variety of exogenous changes in the market, and has behavioral modes that do not appear to match the historical performance of the market. Gately has justified the model on the grounds that it is a plausible behavioral rule for a complex world, but he has also admitted that the ultimate objective of OPEC must be to achieve high revenues. The question naturally arises, then, whether we can build a behavioral simulation model of OPEC that accomplishes that objective directly, without the use of an instrument such as

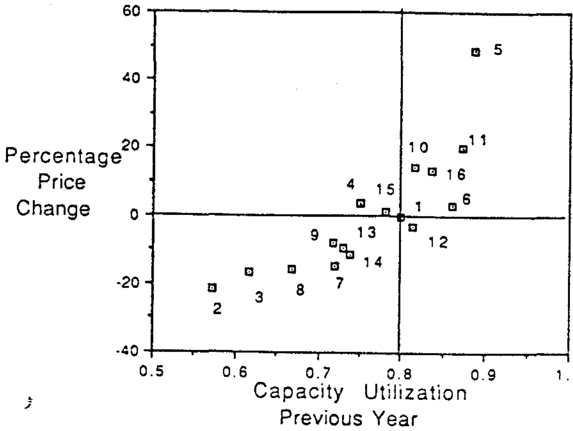

Figure 5. Dynamics of Oil Market Model

capacity utilization. The obvious candidate is a target revenue model, in which OPEC would adjust its price based at least in part on the relationship between current revenues and a revenue target.

There are a variety of ways in which one can construct an OPEC behavioral rule based on achieving a revenue target. One can assume as target a revenue *level*, either fixed or growing exogenously, or one can assume a target growth *rate*. Or one could assume that OPEC seeks to move toward a revenue-maximizing price from the current, possibly sub-optimal state. In addition, there are choices to make about the price-change rule itself. For example, is price changed in relation to the *current* gap between revenue and its target value, or is the price change based on the gap between the target and the *trend* in revenue? Finally, if OPEC were attempting to move to the revenue-maximizing price level it could attempt to estimate the current net elasticity of demand for its oil, and use this estimate along with current revenues to determine the sign and magnitude of the current price change. A complete exploraton of this class of models is beyond the scope of this paper. In the next section we will present preliminary results from a simple target revenue model.

A TEST OF A TARGET REVENUE MODEL

One simple target revenue decision rule uses the gap between current revenues and target revenues to determine the change in price. One way to operationalize this rule is to assume that the price change is zero if revenues are close to the target, and that prices increase or decrease by fixed percentages outside that range. In order to test the performance of a rule of this type we implemented it in the simple world oil model used previously to test the TCU model. Typical results are shown in Figure 6 for a model in which prices increase by 10 percent when revenues are above target, and decrease by 25 percent when revenues are below target. The initial value for revenues is 400; this is also the target level. The model is perturbed by a step increase in demand of 10 units in period five. Demand begins to fall immediately, along with revenue. Prices soon begin to fall as OPEC reacts to the revenue shortfall. As a result demand begins to rise again and revenues increase. Prices continue to fall as revenues are brought back toward the target level. Revenues eventually overshoot the target, but by a small margin, and the overall response of the model to this perturbation is heavily damped.

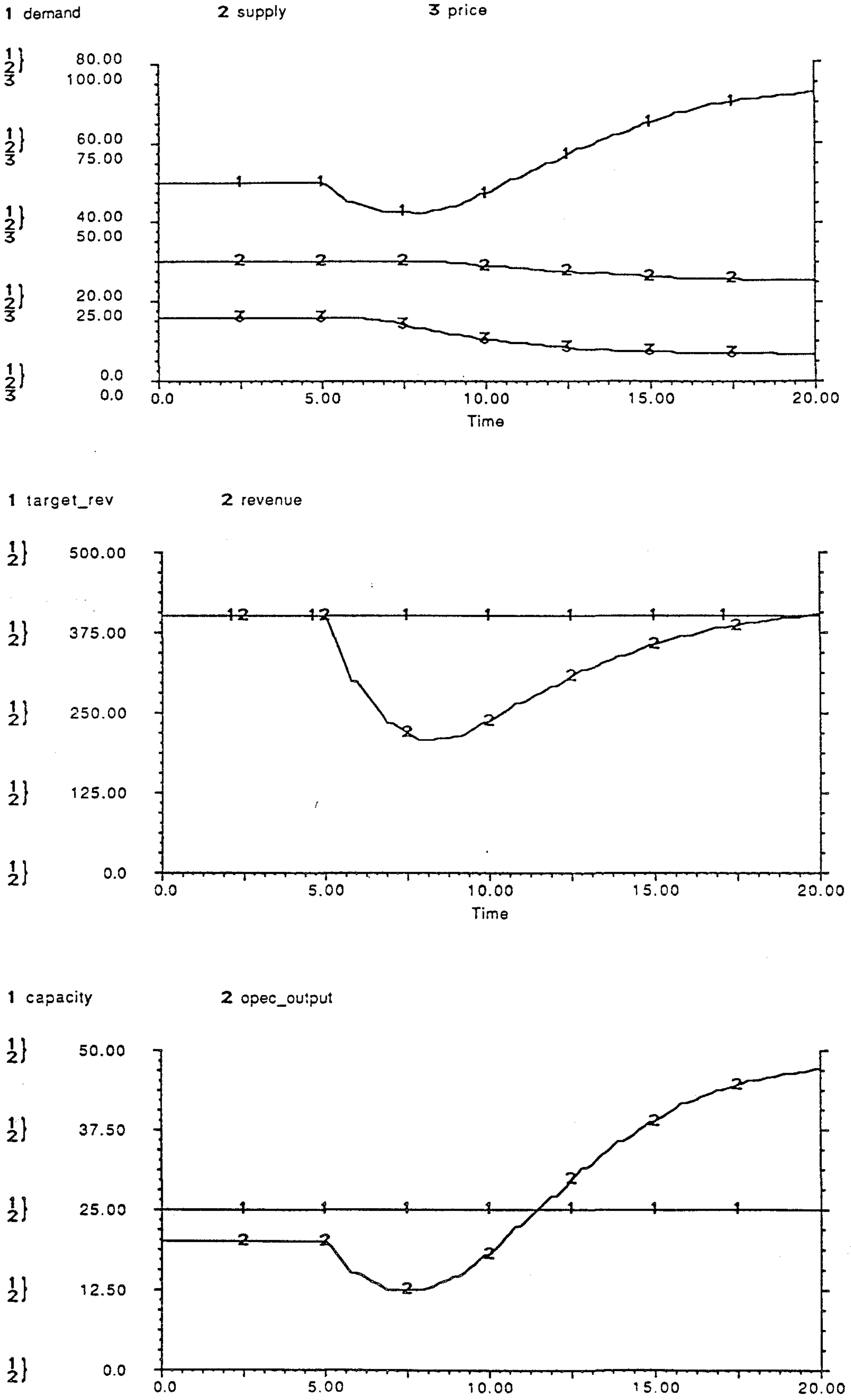

Figure 6. Model Response to 10 MMBD Decrease in Demand

Other tests of this model reveal its other modes of behavior. First, when we perturb the model with an increase in demand the response is similar to that described above. Demand initially rises and revenues exceed the target. As prices increase demand drops and revenues gradually decline toward the target. OPEC output rises initially toward the capacity ceiling, but soon begins to decline and eventually settles at an equlibrium level around 35 percent utilization. In another test we increased both the demand curve and the revenue target by five percent per year. In this case OPEC revenues rise faster than the target, so OPEC continually raises prices to try to close the gap. With the particular traget revenue rule used here the gap widens constantly, so OPEC never succeeds in meeting its revenue target despite a much higher price level. This case illustrates some of the limitations of a simple target revenue formulation to handle a wide range of different situations.

Our analysis of the potential of a target-revenue model of OPEC has been brief. We have tested only one of a myriad of possible implementations of a target revenue decision rule, and that over a small range of cases. Nonetheless, some generalizations are possible. The target revenue rule seems to offer some hope for a realistic behavioral simulation model in which OPEC behavior is tied to its fundamental objectives. However, the model has several shortcomings. First, if the physical constraint on capacity is excluded from the model, the target revenue rule will allow OPEC to produce in excess of capacity. How to include this constraint in a realisitic manner is an open question. The ultimate answer may well involve endogenizing capacity, as suggested by Griffin. Second, the formulation of the target itself and the price change rule have a strong influence on the behavior of the model. How might OPEC change its target over time? How does it learn about market behavior, and how does it incorporate that new knowledge into its decision making? These questions are also open.

SUMMARY

We have evaluated the dominant behavioral simulation model of OPEC, the target capacity utilization model, from a variety of perspectives. We found that the model rests on questionable empirical foundations, that its justification as a plausible behavioral rule does not explain why it is the best such model, and that its performance in a simple model of the world oil market is implausible. We began an exploration of other behavioral simulation models, in particular target revenue models. This class of models has the advantage that it bases OPEC's decision making directly on its objectives. Preliminary results suggest that models of this type might behave reasonably. However, many questions remain. A critical question is how one can determine the most appropriate version of the target revenue model. The historical data is so sparse that it is unlikely to provide a strong discrimination between models. Thus model validation is likely to be a difficult task.

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