The Price of Oil: A System Dynamics Approach

J V Greenman
Department of Mathematics and its Applications
University of Stirling
Stirling, Scotland, UK
FK9 4LA
Tel: +44 786-467460
Fax: +44 786-464551
E-mail: jvg1@uk.ac.stir.forth

Abstract

There has recently been a revival of interest in the dynamics of the oil market, not least because its key determinants are still a matter of intense debate even though the turbulence experienced in the 1970s and early 1980s has largely dissipated.One aspect of the discussion is how to appropriately model the market given that the dominant paradigm of the 1970s - that of exhaustion of a finite resource - is no longer seen to be valid for the short time scales involved. Models that are based on the *behavioural simulation approach* typically use the target-capacity-utilisation (TCU) supply-side model in their description of events but doubts remain as to the validity of the TCU hypothesis. In this paper we adopt a bottom-up approach by modelling as closely as possible, from first principles, the strategies adopted by OPEC in their attempt to manage the world oil market. We also look afresh at the demand side of the oil market to capture the complicated lag structures that characterised the response to price volatility. The complete model, constructed in Stella, is shown to reproduce accurately the hysteresis effect exhibited by the oil market in the period of interest.

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Background

The remarkable story of the oil market in the 1970s and 1980s is well documented (D [1989], Evans [1986]). As a result of political instability in the Middle East the price of o from $5 per barrel (in 1985 US dollars) to over $40 over a space of six years only to colla $10 over the next six years. The complex dynamics involved inspired a major research ef construct models that would give some insight into the processes involved and provide gu on how the market might develop. With the return to a degree of stability in the mid1980s certain disappointment with the overall performance of the models that were built there ha a lull in this area of research activity. The recent revival of interest (Dahl[1990], Powell [reflects the fact that oil is still the world's most important traded commodity and the dyn of the oil market remain sufficiently opaque that debate continues on what are it determinants (Mabro[1993], Gordon [1994]).

The dramatic events of the 1970s led to two radically different interpretations of event dominant school of thought saw the price shocks as the delayed effect of progressive exha of a finite resource. This view was supported theoretically with the exhumation and develo of Hotelling's 1931 theory of exhaustible resources which under simplifying assum predicted an inexorable rise in the price of oil at a rate in line with the real rate of interes disarming simplicity and plausibility of this model and its consistency with the "limits to gr mind-set of the time contributed to its general acceptance, not least by the oil companies made massive investments on the basis of expected rising prices. The price collaps subsequently took place, with real prices falling, at one point, to a level comparable wit before the first price shock, dealt a serious blow to the credibility of the finite re interpretation of events and to intertemporal optimisation as a suitable modelling methodol

An alternative interpretation (Adelman [1990,1993]) saw the events as the result of cartel by OPEC using its power over the market to create and maintain an artificially high pric control was eventually lost and the price collapsed. A variety of simulation models constructed to explore this version of events. One particularly influential model was t Gately [1977],[1983] using the Target Capacity Utilisation (TCU) hypothesis to de supplier behaviour. This hypothesis takes the annual percentage rise in price to be a pie linear function of capacity utilisation. It has recently been tested by Powell [1991] by emb it in a System Dynamics model of the world oil market. He concluded that the empirical ev for the TCU formulation was not as strong as previously thought and that when u simulation generated (sometimes unstable) oscillations that were not characteristic of t market over the last few decades. This, of course, is not conclusive proof since the unr behaviour could be the result of misspecification on the demand as well as the supply side.

In this paper we wish to construct, within the behavioural simulation framework, a new "b up" model of the world oil market that takes into account the abundant and detailed infor (Drollas [1989], Evans [1986]) that now exists on how OPEC reacted to and influenced over the last two decades. On the demand side it is also now much clearer how cons responded to the volatility in the oil market and hence what the dominant features of a demand submodel should be, in particular what lag structures should be included.

The Historical Record.

Before presenting the model we briefly review the events that took place in the oil market 1970s and 1980s.

figure 1: OPEC volumes and real price over time

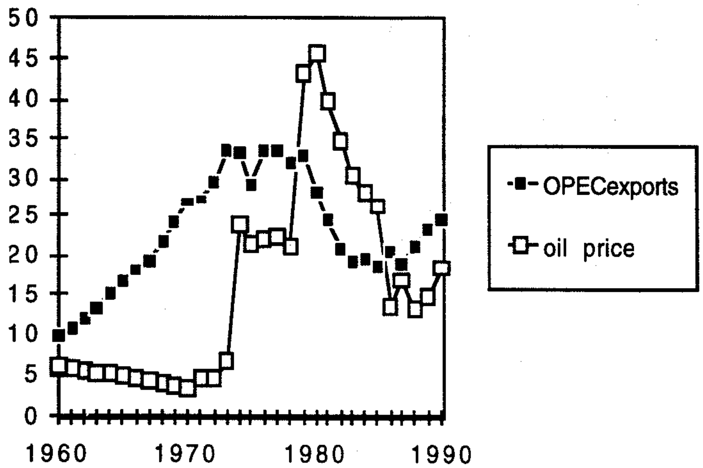
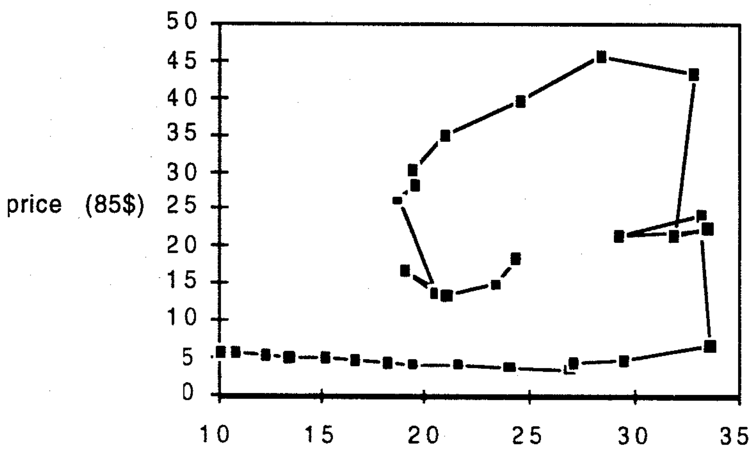


figure 2: The Hysteresis effect - OPEC price vs OPEC exports



In figure 1 we plot, from 1960 to 1990, the volume of OPEC exports and the price of a barrel of oil (in 1985 US dollars). In figure 2 we show the trajectory followed by the market in *phase space* (ie the space of the variables: price and volume). Both figures show the five stages through which the market passed in this period.

* In the first stage, from 1960 to 1970, the price of oil remained essentially constant (at least in nominal terms) as the international oil companies controlled production in order to maintain the price at a level which would ensure OPEC's per barrel revenue. However the oil companies' control over the market became increasingly fragile as inflation in the developed world and the weakening of the dollar led to a slide in the value of oil revenues. The companies were also unable to control the increasing volumes of oil reaching the market from newly developed oil regions by companies not party to the arrangements that had been set up by the major oil companies.

* In the second stage from 1970 to the first quarter of 1974 the price quadrupled. Everyone expected the price to rise - given the significant upward pressure on price - but not that much. This was the period in which OPEC, realising that the market was progressively tightening, began to flex its muscles by demanding not only revenues rising in line with inflation but also a

transference of control over the oil assets - a process that was mostly completed by 1974 uncertainty that these processes engendered led to increased liftings of oil as oil companies s to maximise production ahead of transfer of control and customers increased their purc ahead of expected price rises. However what really shook the oil market was the Arab-Israe with Egypt trying to retrieve the territory acquired by Israel in the previous conflict in Arab members of OPEC used the oil weapon by cutting production and imposing a boyc the US to persuade the Americans to pressure Israel into a ceasefire before its forces annihilate the Egyptian army. Panic hit the world oil market as companies tried to s supplies on the spot market. OPEC, seeing the spot price rise way above its own price pro raised that price to the spot level. Even after the military action had come to a halt the pr was maintained to influence the terms of any peace agreement. Indeed the boycott ar reduction in supply were not rescinded until 1974.

* As peace emerged OPEC decided to maintain the price at its exceptionally high rationalising this decision in terms of North-South politics and exhaustible resource t (Evans [1986]). OPEC was able to keep the price at around $20 in spite of the 1975 rec and against the predictions of those who saw OPEC as an old-fashioned cartel. There we major reasons for this stability. The first was that the oil income for OPEC members w greater than they could absorb at that time and so fluctuations in volume did not have a effect. Secondly after the recession was over there seemed to be little impact on demand (high prices. Demand seemed to be highly inelastic.

* The second shock occurred in 1979-1980 on the back of an already high price lev cause is usually ascribed to the Iranian Revolution in which the Shah was deposed b Ayatolleh Khomeini. The records show, however, that the Revolution was not the direct ca the shock. The immediate cause was the hostile Arab reaction to the signing of the Camp accord between Egypt and Israel with Saudi Arabia suddenly cutting back its production a price sharply rising to $30 a barrel. No sooner had the situation eased than other crises erup the Middle East - with US hostages taken in Iran and religious fanatics storming the Mosque in Mecca. With the fear that the Saudi Arabia would "go up in flames" there was for precautionary oil supplies that pushed the spot price through the $40 per barrel barrier. . it was realised that these worst fears were not justified and the price began to fall Iraq invade with Saddam Hussein attempting to win back the territory that he claimed had been ceded t under duress.

* The fall in price was almost as dramatic as its rise with a concatenation of f conspiring to bring it down. First, there was a deep recession, in part caused by the turbule the oil market and the lack of confidence that that had engendered; second there w increasing volume of oil entering the market outside OPEC's control and competing with oil; thirdly consumers were making substantial progress in reducing their dependence on o using it more efficiently or moving to other fuels. OPEC had thought that the competition oil would be expensive synthetic oil from coal or shale but it turned out to be gas, coal, n and the fifth "fuel": energy conservation. In trying to fix a price and production limit fo OPEC found itself chasing a rapidly moving target as demand for oil plummeted. OPEC me were in a difficult position since they had all embarked on massive programmes of develo based on rising oil prices. It was not until 1986 when OPEC, in desperation, flooded the m with oil that the bottom of the market was identified.

The Supply Side of the Model

Until recently OPEC has explicitly used price as its key policy instrument. The fixation o reflects in part the history of bargaining between OPEC and the international oil compa the period before the latter relinquished control over production. The use of price contr reflects the need for a simple way of coping with a market whose dynamics were only understood.

Different opinions have been expressed on how much control OPEC has exerted over the in its different phases. One particularly clear cut view is that of Mabro who in his recent Energy Journal article (Mabro [1993]) wrote:

> The core has the power to set prices but only when the oil market is slack. When the market is tight, as in 1973, in 1979-1980, and in August-October 1990, prices are set by the market and not by the fiat of core producers.

In this view, the core (ie the major decision makers in OPEC) are followers in a rising market but managers in a falling or weak market. This view is not inconsistent with our description of events but underestimates the contribution of OPEC to the scale of the price rises. After all, it was the action of some members of OPEC that precipitated the crises by restricting supplies - albeit for political rather than economic reasons.

To model the supply side let us start off with the simple "follower-manager" paradigm to generate the hysteresis loop behaviour evident in the phase-space representation of the oil market shown in figure 2. Such hysteresis behaviour, typical of a market subject to cartel action, can be modelled by the following rules:

* in a tightening market, price follows a short-term capacity-constrained supply curve.

* in a falling market, price is maintained until capacity utilisation drops below a certain critical level.

  (ie the cartel cannot indefinitely support an artificially high price if demand proves to be sufficiently elastic).

* production is adjusted to prevent the price falling below a minimum value.

  (Massive excess capacity is, of course, the classic condition for the formation of a cartel with members cooperating to avoid going out of business).

This basic model does not reproduce the two-stage process evident in the price graph of figure 1 with price rising sharply a second time even though demand for OPEC oil was at best static.The essential cause of both the shocks was the imposition of artificial capacity limits or the expectation of such limits. This can be modelled in various ways - the simplest being to vary the capacity in the short term supply function. A more sophisticated approach is to attach a submodel describing the dynamics of the spot market with limited supply.

The decline in the oil price post 1980 was consequent on a sequence of decisions by OPEC about price in the first instance and about the volume of production in the second. The continual misjudgement in identifying where the equilibrium lay - due to the magnitude and the sustained nature of the adjustment process - led to the managed decline in price until the bottom of the market was reached in 1986. This ratcheting down can be modelled in detail or can be proxied by an appropriate rule - for example that the rate of price decline is proportional to the excess capacity over and above a critical level.

Trying out these various possibilities led us to a simple formulation that, when simulated, tracked reasonably accurately the actual trajectory in -phase space (compare figures 2 and 3).

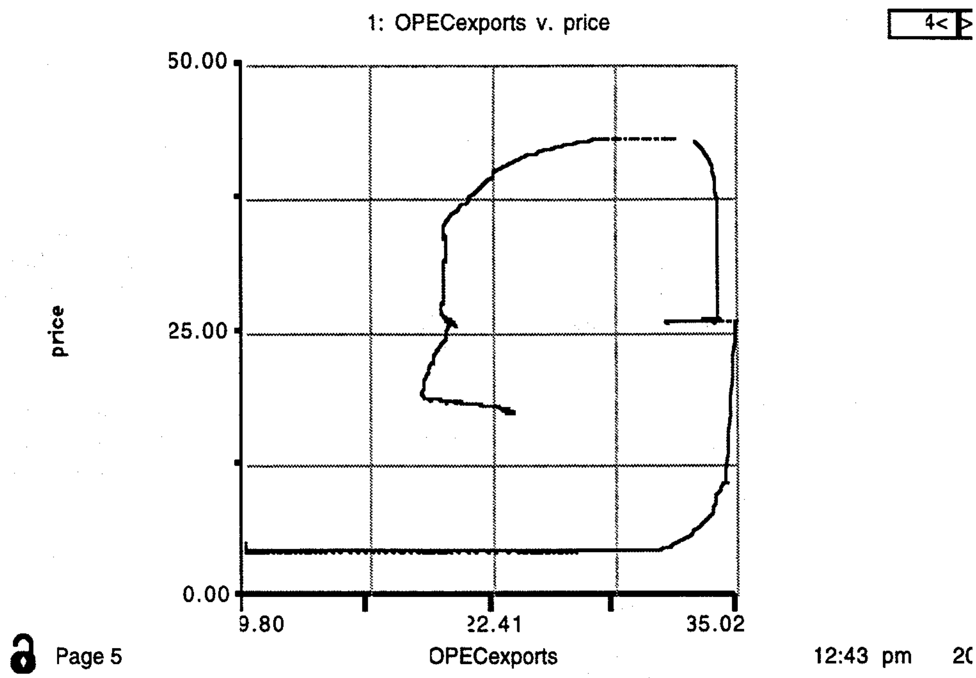
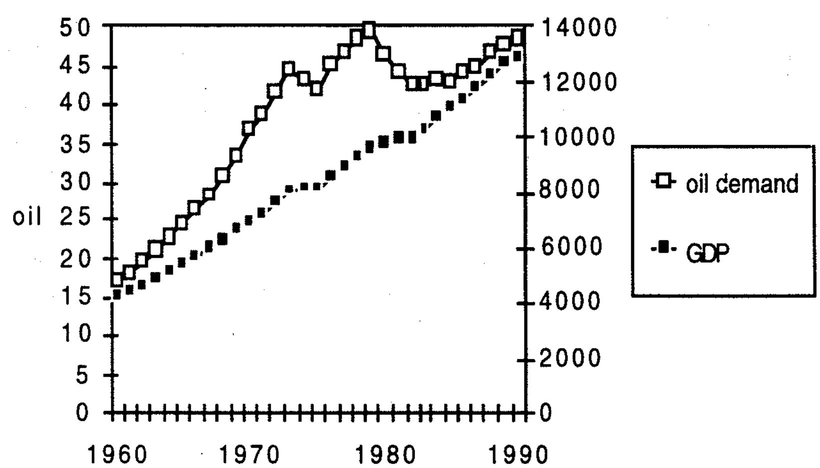


figure 3: Simulation of the Hysteresis Effect

The Demand Side Model

A superficial reading of the data for the non-communist world (NCW) oil consumption o period 1970 -1986 (figure 4) would suggest that after the initial modest response to the firs shock it was very much business as usual until the second shock when the respons unambiguous and sustained.

figure 4: NCW - GDP and oil demand



The apparent lack of response to the first crisis reflected the fact that changes involving equipment take a considerable amount of time to work through. One clear example of tl the imposition by the US Congress of the "CAFE" standards that obliged manufacturers to double, over the decade, the fuel efficiency of their vehicles or face heavy financial penalties. The effect of this policy, introduced in the mid 1970s, was not felt until the early 1980s. There were also major changes taking place in the market shares of different fuels. In the electricity generation sector, for example, nuclear power was capturing a significant share of the market in the developed world, backing out oil in the process - especially in Europe.This process was, in fact, set in train before the first oil crisis and had little to do with the high price of oil but this was not the case with the expansion of the gas market in Europe with new supplies coming from the North Sea and Russia. Domestic users, in particular, were preferring gas to oil but bringing on stream these new supplies was costly and took time. The impact was not evident until the early 1980s.

To capture the major effects on the demand side in a simple model requires some care. It is relatively straightforward to fit a lagged loglinear model but difficult to make sense of the parameter values in terms of the various factors contributing to the dynamics. An alternative model is proposed which explicitly articulates two processes central to the rapid decline in oil demand in the early 1980s (figure 4), namely retirement of oil burning plant and the switch to other fuels where possible in new plant. The proportion of investment in oil-burning plant is taken to be a lagged function of relative price and the rate of plant depreciation and the utilisation of plant to depend on the price level and on the growth rate in the economy. These assumptions yield a demand-side model with second-order lag.

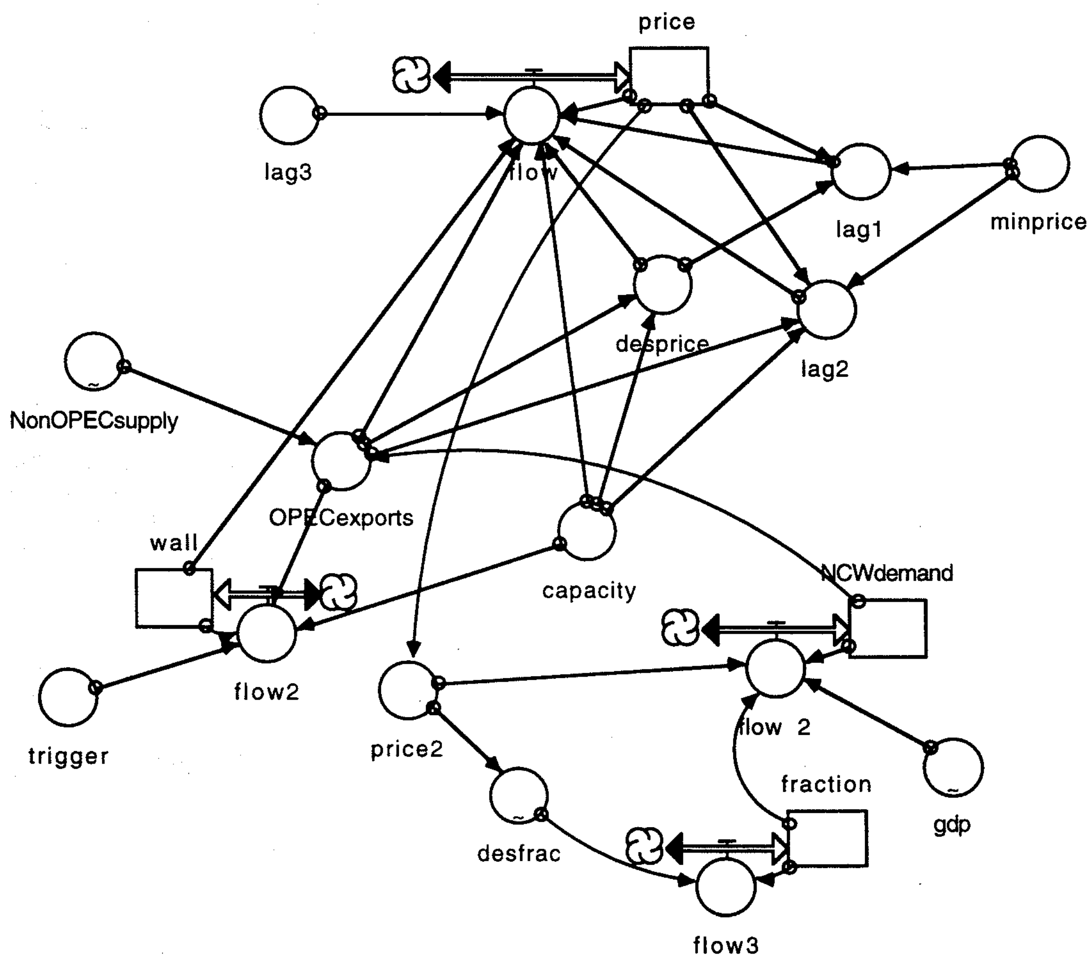


figure 5: The Stella Diagram for a Model of the World Oil Market

The Stella diagram for the model linking the supply and demand submodels is shown in figur The supply submodel refers to OPEC export volumes and the demand side to NCW consumption. The connection between the two is made by adding (exogenous) non-OPEC sup Simulation of the model after grid-search calibration is shown in figures 3 and 6.

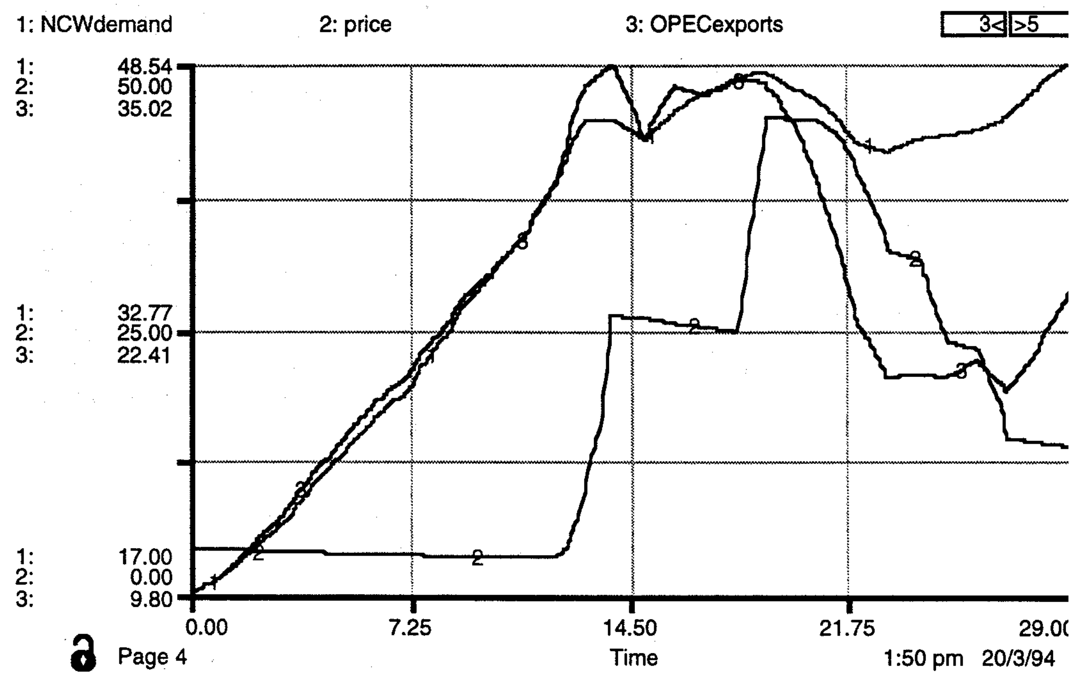


figure 6: Simulation with the Stella model.

Explorations

A common criticism of behavioural simulation models is that they are ad-hoc with decisions n by rule of thumb rather than in accord with a simple fundamental economic principle. Certa the 'rule of thumb' approach lacks the intellectual coherence of a model built on 'so principle but even so there is a reputable literature devoted to ad-hoc decision making. It m also be said that the 'rule of thumb' approach often makes up for the lack of rigour by provi a more realistic description of actual events. For the system modeller, of course, the g advantage of the behavioural simulation approach is that it is 'open', allowing the user to int with the model to explore whatever scenarios are of interest.

For the world oil market we are interested in two issues (i) what would have been the best stra for OPEC from 1970 onwards given the dynamics as specified by the model and (ii) what opt decision rule does the model suggest? The latter requires a dynamic programming approach both would benefit from a stochastic treatment. We hope to report on these investigat elsewhere.

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