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The Myth of the OPEC Cartel

The Role of Saudi Arabia

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CHAPTER 4

The Economics of Exhaustible Resources

4.1 THE FORMAL MODEL

Natural resources whether exhaustible or not, are assets of the society in that they can yield streams of services to the society over future periods. But certain features of natural resources may distinguish them from other assets. These features include the externalities that arise in the production and consumption of services derived from natural resources, the appropriability properties of natural resources, and whether such resources are replenishable or not.

In the case of Saudi oil there is no problem with either appropriability (ruling out foreign intervention) or externalities. The government is the sole owner of all of the country's natural resources. Thus, property rights are well defined, enforced, and transferable and externalities that arise due to the divergence between social and private costs are absent.

Oil, of course, is exhaustible in the sense that society's stock of the reserve could not be physically replenishable. The difficulty in the concept of exhaustion is that geologists estimate the 'stock' of oil in terms of 'recoverable' reserves. But what is recoverable depends on the cost of extraction relative to the price of oil. Every increase in the price of oil or decrease in the costs of its extraction increases the world's stock of recoverable oil. In addition, an increase in price will lead to more search and that usually results in increasing reserves.

In a physical sense, all minerals are limited because the crust of the earth is. Shale oil, tar sands, coal, and uranium are all limited. The difference between them and oil is that oil is at this time cheaper to extract and use. When it becomes more expensive than all the others, we stop searching for it and use the others before we get to the last drop of oil that the earth contains. Thus oil is really inexhaustible in a physical sense, but, for the purposes of economic analysis, exhaustion occurs once it is cheaper to use other sources of energy.

For our purposes we will define the exhaustion of oil in the following way (Quirk, 1976: Chapter 18):

Given prices of oil and substitutes and a state of technology in period t, the oil reserves R at $t + 1$ are equal to reserves during the t period minus actual output q in the t^{th} period, or

$$R_{t+1} = R_t - q_t$$

The problem that an owner of an exhaustible resource faces is how much output should be produced in each period of time until the costs of production exceed the revenues, i.e., exhaustion. To answer this question we have to make some simplifying assumptions.

The mathematics could be challenging and may involve multivariate control problems which are very difficult to solve. Happily, James Quirk had shown that all the important results could be derived by using simple algebra.

Assume that (1) there are many producers and each acts as a perfect competitor, (2) marginal cost (*MC*) is positive, and (3) marginal cost increases as the stock is depleted. New discoveries may occur and thus *MC* may not rise, but the point is that producers must have some estimate of such events and eventually *MC* must rise.

The owner of any resource, say oil, will manage his stock so as to maximize the discounted present value (DPV) of the time stream of income from his holdings of the stock:

$$\text{DPV} = \frac{P_1 q_1 - C(q_1, R_1)}{1 + r} + \frac{P_2 q_2 - C(q_2, R_2)}{(1 + r)^2} + \ldots + \frac{P_n q_n - C(q_n, R_n)}{(1 + r)^n}$$

where P_t and q_t stand for price and output; R_t is the estimated and probable reserves; $C(q_t, R_t)$ are the total costs of mining (not just the extraction costs); and r is the discount rate. The owner of the resource wishes to maximize DPV. This is accomplished by choosing his output rates such that

$$\frac{\Delta\text{DPV}}{\Delta q_t} = 0 \text{ for each } q_t$$

given that for any R_i, increasing output in the t^{th} period reduces the amount that could be mined in the future and assuming that $q_t > 0$. This condition is equivalent to the static rule of choosing output q such that $\Delta\pi/\Delta q = 0$.

An increasing Δq_t in the amount mined in period t increases the net cash flow in the same period by the amount

$$(P_t - MC_t)\,\Delta q_t$$

But this increase in output reduces the stock available to be mined in period $t + 1$ by Δq_t. Assuming no change in mining rates in periods $t + 2$, $t + 3, \ldots . t + n$, the net cash flow in period $t + 1$ is reduced by

$$\left(P_{t+1} - MC_{t+1} + \frac{\Delta C}{\Delta R_{t+1}}\right)\Delta q_t$$

The overall effect on DPV of an increase in output by Δq_t is then given by

$$\frac{(P_t - MC_t)\Delta q_t}{(1 + r)^t} = \frac{\left(P_{t+1} - MC_{t+1}\frac{\Delta C}{\Delta R_{t+1}}\right)\Delta q_t}{(1 + r)^{t+1}}$$

Thus the rule $\Delta\text{DPV}/\Delta q_t = 0$ implies that

$$(P_t - MC_t)(1 + r) = P_{t+1} - MC_{t+1} - \frac{\Delta C}{\Delta R_{t+1}}$$

or

$$P_{t+1} - P_t(1 + r) = MC_{t+1} - MC_t(1 + r) - \frac{\Delta C}{\Delta R_{t+1}}$$

This last expression has a meaningful economic interpretation. Suppose there are no variable costs, and so the right-hand side of the expression is zero. Then, if the resource owner supplies positive amounts of the resource in each period, the price per unit must rise over time at a rate equal to the market rate of interest. That makes a lot of sense. For if $P_{t+1} < P_t(1 + r)$, then the owner should sell his entire stock in period t and invest the proceeds in assets earning the market interest rate.

If, on the other hand, $P_{t+1} > P_t(1 + r)$, then he should sell nothing in period t since he can earn more than the market rate of interest by leaving his stocks in the ground and making the sale in period $t + 1$.

The fact that variable costs are positive complicates things, but the basic idea holds. Before we try to apply this general principle, let us examine what we meant by 'total costs of mining'. In general, mining costs consist of two components: (1) extraction costs or operating costs, and (2) user cost.

Extraction costs are the familiar costs of production. User cost is the increase in cost which is caused by the reduction of the total stock of the resource. That is, the total stock of resources remaining affects the costs of mining. And, since production typically takes place over many periods of time, user cost is determined by the whole future path of costs and prices and not just by current conditions.

In the case of oil, marginal production costs (*MC*) are close to zero, but user cost, $\Delta C/\Delta R_{t+1}$, is positive. This means that positive output in each period implies that price must rise faster than the rate of interest, since

$$P_{t+1} - P_t(1 + r) = -\frac{\Delta C}{\Delta R_{t+1}}$$

when

$$MC_t = MC_{t+1} = 0$$

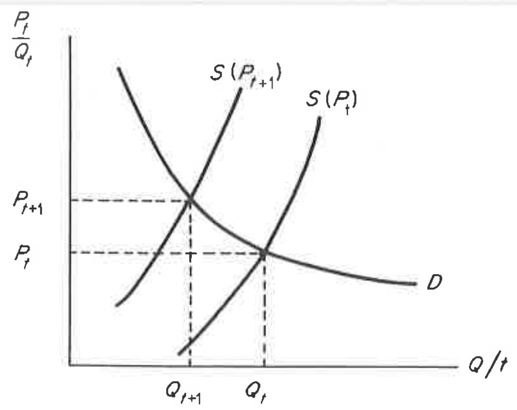

Figure 4.1. Price changes over time in the case of an exhaustible resource.

Since each resource owner will follow this rule, the market for oil will be as depicted in Figure 4.1. Assuming that the demand schedule in each period is unchanged over time (in fact it has been increasing), the market equilibrium is as shown. At each period of time the market supply curve $S(P)$ is the sum of the supply curves of individual producers. At $t + 1$, the supply curve $S(P_{t+1})$ lies to the left of the supply curve $S(P_t)$, because output in period t, Q_t, reduces the stock available for mining period $t + 1$ and, hence, increases the cost of mining any given output in future periods such as $t + 1$. The higher the interest rate, the further to the left is the $S(P_{t+1})$ curve.

As a result, the market price rises over time. If it turned out that large and unexpected new discoveries were made, then the price may not rise. In the case of oil—contrary to what is generally being assumed—no major and unexpected discoveries were made since the late 1950s.

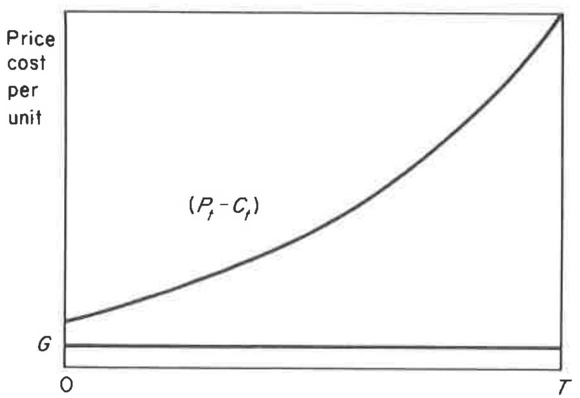

Figure 4.2. The behaviour of price over time in the case of constant costs.

For an individual producer, the case of constant cost is illustrated in Figure 4.2. OG is cost per unit, which remains constant over time. The deposit will be exhausted at time T when the price brings the quantity demanded to zero.

4.2 THE THREAT TO PROPERTY RIGHTS

But how could we reconcile the facts of the oil market with the predictions of this economic model? Firstly, the real posted price of oil between 1947 and 1970 decreased by approximately 65 per cent, even though the interest rate was slowly rising (Adelman, 1977). Secondly, the demand for oil was not constant but rose by about 7 per cent per year. Thirdly, no major and unexpected new discoveries were made since the late 1950s. Was the cost of extraction falling? No, it was not; and the user cost, of course, was rising.

There are two main reasons why the real price of oil in fact fell rather than rose as our analysis predicted.

The first reason is that the 1947 price of oil was not determined by competitive forces. It was in fact greatly influenced by the Texas Railroad Commission, who instituted demand prorationing to keep prices higher than what they otherwise would have been. Once an oil price was 'posted' at the U.S. Gulf of Mexico, it was then used as the basis of the price of oil throughout the world.

The second reason for the fall of the price of oil has to do with the problem of oil appropriability in the Arabian Gulf. Since the end of World War II, the Arabian Gulf gradually replaced the US Gulf of Mexico as the most important oil-producing area. The governments of the Arabian Gulf signed agreements with the western oil companies to produce oil. But these agreements did not prevent the governments from increasing the oil royalties and threatening the oil companies with nationalization.

Increasing royalties and fear of nationalization increased the oil companies' expected future costs. That led the companies to increase their oil production by greater rate than if they did not expect future costs to rise. The increase of supply of course led to the fall of prices. A lot more will be said about this in Chapter 5.

The influence of the presence of a threat to the oil companies' property rights on their rate of oil production could be shown formally and more clearly by using the following model.

First let us clarify the notation:

P_t = the unit price of oil in period t
C_t = the average cost of extracting a unit of oil in period t
$R_t = P_t - C_t$
r = the market interest rate

Assume that, as far as the oil companies were concerned, $dc/dt = 0$. Under a world of certain and well-defined property rights, an oil company will supply a positive amount of oil in periods (t) and ($t + 1$) if it expects

$$R_{t+1} = R_t(1 + r)$$

But the oil companies knew that there was always some threat to their property rights in the OPEC countries. The probability of expropriation varied among countries, but the companies were never one hundred per cent certain that their property rights would not be threatened.

Let us say there is a probability $q < 1$ that nothing will interfere with their operations. Then,

$$E(R_{t+1}) = q(R_{t+1}) + (1 - q)0$$

or

$$\hat{R}_{t+1} = q(R_{t+1})$$

Now they will supply oil in period (t) and period ($t + 1$) if

$$\hat{R}_{t+1} = R_t(1 + r)$$

That is, R_{t+1} must be greater than $R_t(1 + r)$ in the case of uncertainty. In other words, qR_{t+1} (rather than just R_{t+1}) should be equal to $R_t(1 + r)$, or

$$R_{t+1} = R_t \frac{(1 + r)}{q}$$

The effect of less than 100 per cent certainty about future property rights is to increase the effective rate of discounts, r, that the oil companies will base their decisions on. For example, say the market rate of interest, $r = 10\%$, and, say a company thinks that the probability q that no one will

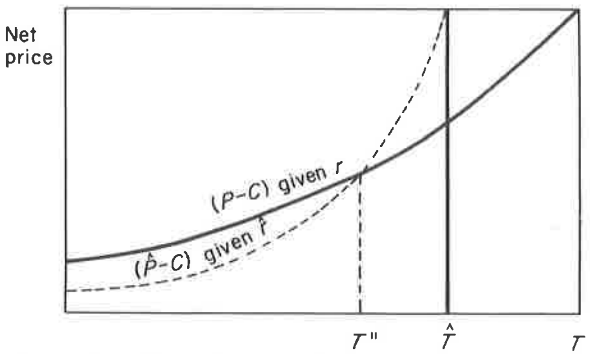

Figure 4.3. The influence of increasing the discount rate on prices over the time and on the date of exhaustion.

interfere with its operations is 0.75. Then

$$\hat{R}_{t+1} = \frac{R_t(1 + 0.1)}{0.75} = R_t(1 + \hat{r})$$

That is,

$$1 + \hat{r} = \frac{1.1}{0.75} = 1.47$$

or the company's effective discount rate is 47 per cent when $r = 10\%$, $q = 0.75$. The influence of increasing the discount rate on an oil company is obviously to increase its rate of output which in turn decreases the world's oil price. As long as $q < 1$, however close it may get to 1, the effective discount rate $\hat{r}$ will be greater than the market rate of interest, r. Figure 4.3 shows two possible paths of $(P - C)$, given $\hat{r} > r$.

It is to be expected that uncertainty will result in greater rate of output. What is surprising is the fact that at $q = 0.75$, a very reasonable approximation, the effective discount rate has changed from 10 per cent to a huge figure of 47 per cent.

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