THE INTERNATIONAL CRUDE OIL PRICES, 1957-76: AN EXHAUSTIBLE RESOURCE AND AN IMPERFECT COMPETITION

by

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INTRODUCTION AND PLAN OF THE STUDY

The method of partial equilibrium analysis known as "price theory," has gained acceptability and respect. Nevertheless, both the validity of the theory and its application are controversial. Some economists believe that price theory not only explains market behavior, but also explains human behavior outside the monetary market framework. On the other hand, critics argue that price theory does not explain or predict even the market behavior. These critics deny the validity not only of analytical investigations, but of the empirical studies as well. Typically, they believe:

> The use of mathematics, estimated statistics, and the computer have only given the illusion of certainty to the work of those who have sought either to quantify economic activity or to predict the future. These predictions are neither more nor less than what they have always been--guesses. (1)

The market behavior of the international oil industry is often presented as an example of the apparent failure of price theory. The economic analysis of the market is not correct because, the critics say, the predictions and conclusions are obviously incorrect.[2]

The fallacy of this reasoning is clear: the failure of a given prediction does not imply that the prediction is unwarranted. That certain economists failed to analyze the market precisely does not indicate that the theory is insufficient. Nevertheless, the theoretical and empirical literature presenting the economic analysis of the petroleum industry does lack an acceptable explanation of the price changes of the resource. Of the three elements which determine the price of petroleum (cost-output function, demand function, and the degree of competition),the cost-output function and its fundamental changes are the least understood and require considerable attention.

One goal of this study is to present a tenable analytic framework for the study of the international crude oil supply conditions so that the role of the price theory in explaining and predicting the price changes of world crude oil may be explored. As a source of energy (from the consumers' point of view) and/or as an exhaustible resource (from the producers' point of view), crude oil is a subject of national concern in each country. These and other factors must be considered in explaining the observed patterns in the world oil industry. A comprehensive analysis of the world oil market is not attempted here; instead, attention is directed to certain basic supply characteristics. An acceptable measure of the cost will be defined in order to estimate the supply function for each country or for the Organization of Petroleum Exporting Countries (OPEC).

Oil is by far the leading commodity in international trade and therefore there is no shortage of the literature dealing with the various aspects of the industry including so-called political and economic analyses. Nevertheless, despite the enormous quantity of miscellaneous information on the world petroleum industry, relatively little has been written or reported on the techniques or theory of the pricing of crude oil. Frank (1966)[3] examined the determination of the price of oil as an olygopolistic behavior. Rifai (1974)[4] considered and examined the informal, technocratic and strategic approach to crude oil prices. Bradley's empirical studies (1967)[5] include the measurement of the cost of crude oil for some regions in the Middle

East. Adelman (1972)[6] presented a comprehensive analysis of the world oil market, skillfully calculated the cost, and predicted the market price of the resource for the coming years up until 1985. Each of these studies are valuable. Their contribution to the literature is appreciable, and their predictions may be considered "warranted"[7] and "correct." However, in recent years, related events have caused substantial changes in the nature of the supply function. Therefore, not only those predictions but also the method of the analyses require reconsideration.

In order to analyze the supply function of petroleum, as with any other natural resource, it is necessary to determine whether or not the resource is economically exhaustible, i.e., whether its scarcity rent is sizeable or negligible. A resource may be considered economically inexhaustible for certain periods and exhaustible for others. In the literature mentioned above, the question of exhaustibility has either been ignored or declared unimportant. Such views were considered acceptable until the late 1960's for the following reasons:

(1) The price system is the main social institution evolved by capitalist economies (and, to an increasing extent, socialist economies, too) for registering and reacting to relative scarcity.[8]

(2) If the market price of a commodity is higher than its marginal cost because of monopoly power, the gap between the price and the marginal cost must be narrowed over time; i.e., the price must move downward toward the marginal cost.

(3) Because the relative price of crude oil until 1970 was a decreasing function of time,[9] it is possible that the market price

included monopolistic profits but not scarcity rent.

It is the hypothesis of this study, however, that petroleum has become economically exhaustible. Subsequently, its analysis must be considered within the framework of "the economics of exhaustible resources."

This paper consists of three chapters. The first considers the courses of price and rate of extraction of an exhaustible resource under the conditions of perfect competition and of monopoly. The second briefly describes the international oil industry, its forces and their changes over time in order to provide a background for the analysis which will follow in Chapter 3. The last chapter reports the results of empirical studies which explain the variation in the prices of international crude oil through the related explanatory variables. In short, the final chapter is the application of the model presented in Chapter 1 in order to explain the changes of the prices caused by the events described in Chapter 2

FOOTNOTES

[1]Karl F. Simpson, (Letter), Harper's September 1975, p. 12. See also: Saul Friedman, "The Dismal Religion: Economics as Faith Healing," Harper's, July 1975, pp. 27-36

[2]As a sample, see: M. A. Adelman, The World Petroleum Market, (Baltimore: Johns Hopkins University Press, 1972), 1:

> "The official truth in the capitalist, communist, and third world is that crude oil is becoming ever more scarce, special measures are needed to assure its provision, and prices will rise. But the conclusions of this study are that crude oil prices will decline because supply will far exceed demand even at lower prices, and because--a separate issue--there will continue to be enough competition to make price gravitate toward cost, however slowly. The official truth has ruled for 25 years and has not much resembled the facts."

[3]H. J. Frank, Crude Oil Prices in the Middle East: A Study in Oligopolistic price behavior, (New York: Praeger, 1966)

[4]T. Rifai, The Pricing of Crude Oil, (New York: Praeger, 1974).

[5]P. Bradley, The Economics of Crude Oil Production, (Amsterdam: North Holland Publishing Company, 1967).

[6]M. A. Adelman, The World Petroleum Market, (Baltimore: Johns Hopkins University Press, 1972).

[7]A prediction can be called "rational" or "correct" or "warranted" in terms of the accepted rules of scientific procedure if it is inferred from the whole body of (relevant) knowledge available at the time at which it is made.

[8]See R. M. Sollow, "Is the End of the World at Hand?", Challenge, March-April 1973, pp. 39-50.

[9]See W. D. Nordhaus, "Resources as a Constraint on Growth," The American Economic Review, May 1974, pp. 22-32.

CHAPTER 1

PRICE, DEPLETION RATE, AND THE SUPPLY OF AN EXHAUSTIBLE RESOURCE

The main purpose of this chapter is to find an economic answer to the following question: "What determines the (quasi) supply function of an exhaustible resource for a firm and how can it be derived in case of imperfect competition?" In order to provide a background for the analysis, I will present the definition of an exhaustible resource and its prices followed by a review of theoretical literature. I will then indicate the form of study.

An Exhaustible Resource

The starting point for the study of the economics of exhaustible resources is the definition of the term "exhaustible." There are two meanings for the word "exhaustible." The first is the dictionary definition, i.e., "that which can be exhausted"; in this sense, everything in the world is exhaustible. The second meaning has become an economics term: "A resource which can never increase its stock through time. It can only decrease or, if unmined for a while, remains the same." Whenever we use "exhaustible" in this paper, we exclusively mean the economics term and nothing else. Therefore, wheat is an inexhaustible commodity but ore is an exhaustible resource. We should bear in mind that forests or stocks of fish are not exhaustible resources because they are replaceable over time; aluminum or iron, however, even though they are recyclable, are exhaustible resources because the laws of Thermodynamics guarantee that we will never recover a whole pound of primary iron in use. It is impossible to build a machine with 100% efficiency. Thus iron, for example, remains an exhaustible resource despite the possibility of partial recycling.

There are two kinds of exhaustible resources, those which are renewable and those which are not renewable in this stage of technology. Some of the metals, if not all, are classified in the former category while petroleum is classified in the latter. Since the main theme of this paper is the economics of international crude oil, and it is non-renewable, we will study and analyze those exhaustible resources which are not renewable. That is, whenever we use the term "exhaustible resource," we exclusively mean that kind of resource which cannot be recycled.

The Price of the Resource

There are two different prices for an exhaustible resource, namely, "scarcity price" and "price in the market." The scarcity price of a resource is the market price of the resource when it is in the ground. Some authors call this price "scarcity rent." The price in the market is a summation of the price in the ground plus extraction and transportation costs, and profit.

Quality differences, such as the varying concentration of metals in different ores, affect the price of a resource. The mineral industries generally handle this by the contained metal approach. One measures the metal contained in the ore, rather than the gross weight of the material. This approach seems appropriate here since it permits us to include all deposits of the same material. Quality differences become cost differences.

Whenever the term "price" is used in this paper, we mean "net price," i.e., the price in the ground, unless otherwise stated. This convention is equal to the assumption that extraction and transportation costs remain the same through time:

Price in the ground = price in the market - all costs.

If "all costs" for a unit of the resource are constant through time, then all the changes which may happen for price in the market will transfer to price in the ground and vice versa.

A REVIEW OF THEORETICAL LITERATURE

A pioneering article by Lewis Gray in 1914 entitled "Rent Under the Assumption of Exhaustibility," presented the basic propositions relating to the individual firm. He used verbal analysis supplemented by numerical examples[4], to ingeniously distinguish between two kinds of behavior: behavior of the land owner (indestructable asset), and the behavior of the mine owner (exhaustible asset). Gray says,

> According to the Ricardian theory of rent the landowner will find it to his interest to add units of labor and capital to a given surface of land up to the point where the last unit applied just equals the product which might be derived from its employment on marginal land. In familiar phraseology, labor and capital are added up to the intensive margin of cultivation. According to the theory, such a ratio between the factors of production will yield the maximum rental to the landowner, under the given conditions. The exhaustibility of the natural resource, however, dictates a different course. The owner of the mine may well hesitate to proceed beyond the point of maximum average returns per unit of expense. At this rate of removal the average net return per ton of coal is a maximum, since the average expense of removal per ton is a minimum. (4)

Hotelling's classic article, "The Economics of Exhaustible Resources"[1] (1931) provided the fullest treatment; he gave a more precise definition of exhaustion, developed a mathematical-analytical framework, and outlined the analysis of several basic cases.[5] In Professor Solow's words: "Like all economic theorists, I am in his debt."[6]

It is unfortunate that the whole issue of exhaustion was almost neglected until very recent years. During the 1950's we can see one article by Herfindahl.[7] In this article he used average and marginal cost curves to show Gray's analysis. During the 1960's, fortunately, there were several good articles. These works have concentrated on amplifying portions of Gray-Hotelling's work. Anthony Scott[8] developed a more general geometric approach that could deal with complications produced by forces such as shifts of prices and cost over time. His conclusion is that the rational mine manager will tilt his production plan in favor of the present instead of producing at a constant annual rate. He will do this because of the ever-shortening future life of the mine, even in the absence of conditions such as deterioration of ore quality, or falling prices and rising costs. This is because of the rising value of what Professor Scott calls the user cost of mining as exhaustion shortens the future life of a mine.[8]

It was mainly the publication of The Limits to Growth, publicizing of the so-called "Doomsday Models," the world-wide attention to the advancing scarcity of some raw materials in the world, and finally a global enigma (or dilemma) termed the "energy problem" which have demanded that economists pay more attention to the Economics of Exhaustible Resources. A leading article on this topic is Professor Solow's "The Economics of Resources or the Resources of Economics" (1974). Solow restated clearly the neoclassical conditions necessary for efficient utilization of an exhaustible resource which were explored by Hotelling.

Concerning the problem under investigation, the theoretical literature can be summarized as follows:

1. Behavior of a firm when the market is perfect competition.

Case A: Unit extraction cost is constant or negligible. In this case the owner is indifferent to selling all, part or none of his mine in the present period, i.e., his supply function is perfectly elastic.

Case B: Average cost function has the familiar U-shape (Figure I-1) and it is constant through time.

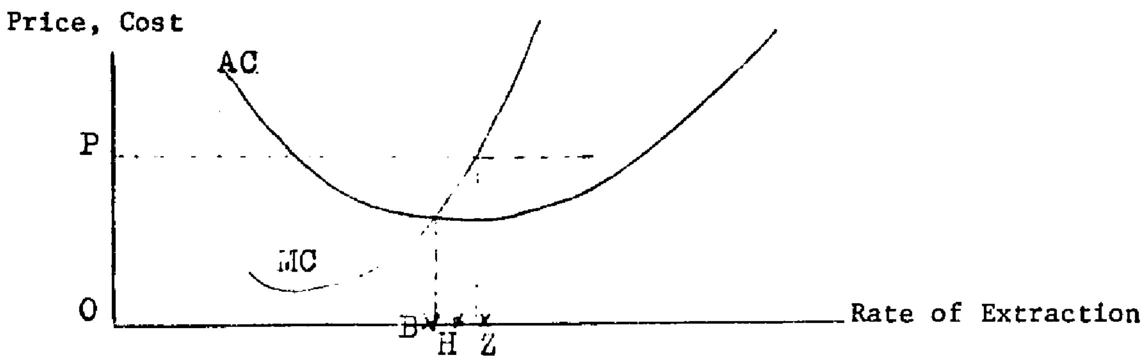

Figure I-1. Optimum rate of extraction for a firm

Gray[4] believed the rate of extraction is OB. But Scott[8] suggested that the firm will tilt its production plan in favor of early periods, placing the rate somewhere between OB and OZ, such as H, where in early periods OH is closer to OZ but in later periods it is closer to OB.

2. Behavior of the industry when the market is perfect competition. The literature is mostly concerned about the course of the price of the resource and its rate of extraction. Since it is a matter of indifference to the owner of a mine whether he receives for a unit of his product a price P_o now or a price $P_o e^{it}$ after time t

(where e^{-it} is a discount factor), it is not unreasonable to expect that the price P will be a function of the time of the form $P_t = P_o e^{it}$.[1] In other words, if each year during the period of exploitation is to have some production, no year can be more attractive to an owner of a deposit than another, for if it were, he and all his brethren would shift production to that year. It means that the present value of a mine at different points in time must be the same.

This is the fundamental principle of the economics of exhaustible resources, and was the basis of Hotelling's article. He thought of it mainly as a condition of flow equilibrium in the market for the resource: if price is increasing like compound interest, owners of operating mines will be indifferent at the margin between extracting and holding at every instant of time. Solow deduced it as a condition of stock equilibrium in the asset market:

> A resource deposit draws its market value, ultimately, from the prospect of extraction and sale. In the meanwhile, its owner, like the owner of every capital asset, is asking: What have you done for me lately? The only way that a resource deposit in the ground and left in the ground can produce a current return for its owner is by appreciating in value. Asset markets can be in equilibrium only when all assets in a given risk class earn the same rate of return, partly as current dividend and partly as capital gain. The common rate of return is the interest rate for that risk class. Since resource deposits have the peculiar property that they yield no dividend so long as they stay in the ground, in equilibrium the value of a resource deposit must be growing at a rate equal to the rate of interest. Since the value of a deposit is also the present value of future sales from it, after deduction of extraction costs, resource owners must expect the net price of the ore to be increasing exponentially at a rate equal to the rate of interest. (2)

Using the familiar geometric approach, the course of price and depletion rate can be shown by Figures I-2 and quadrant 4 of Figure I-4, respectively.

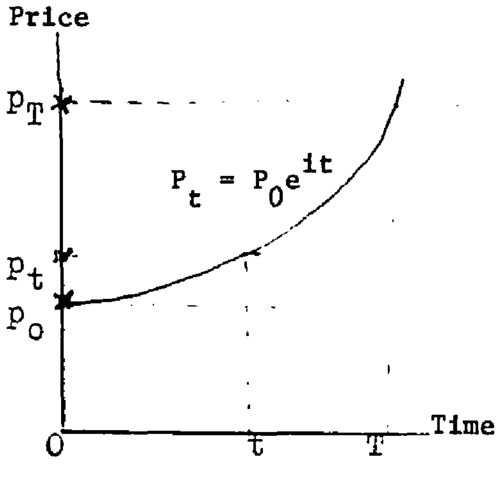

Figure I-2.

The course of price over time

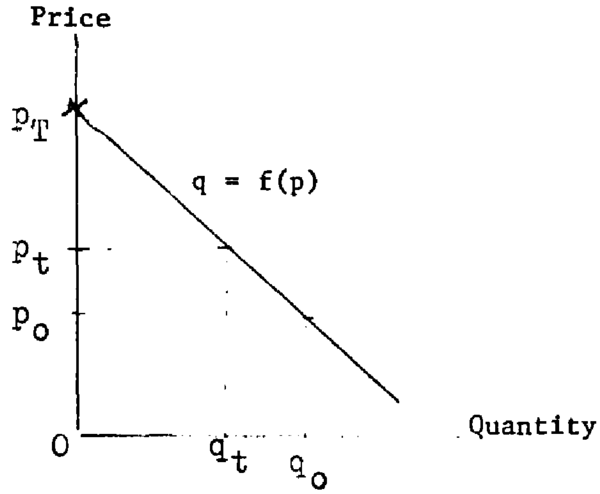

Figure I-3.

Demand for the resource

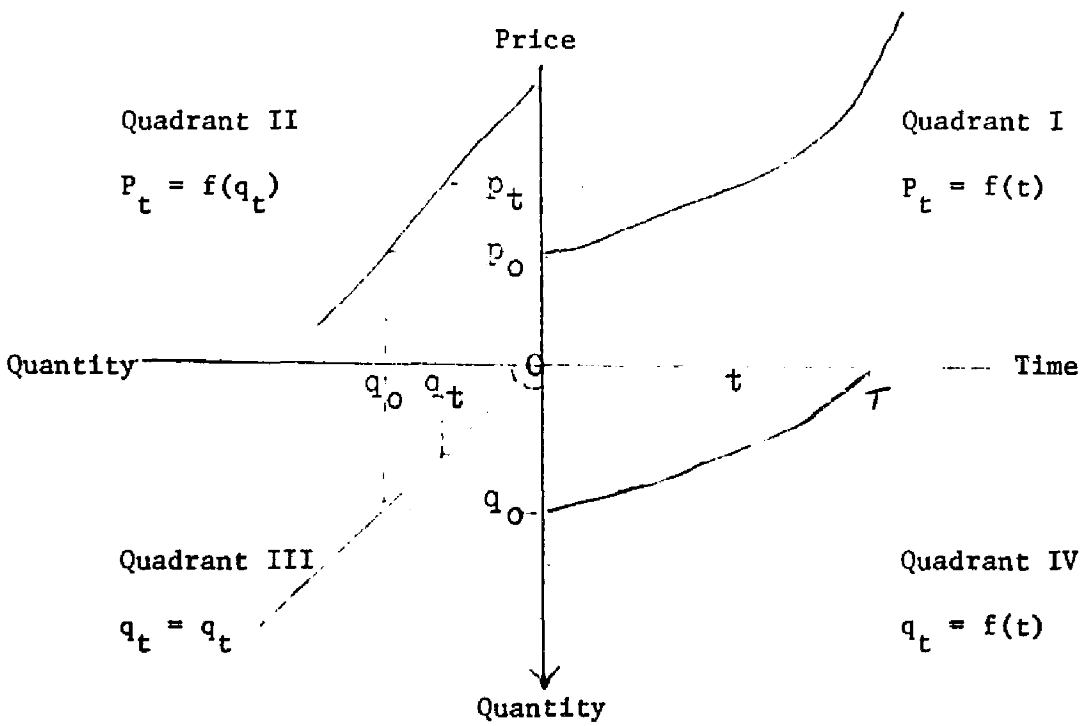

Figure I-4.

The course of price and depletion rate over time

3. Monopoly. Hotelling considered a very simple case where demand is known and remains constant through time. For each period the monopoly's revenue (in the absence of production cost revenue is the same as profit) is $y = pq$. The monopoly's objective is to maximize the present value,

$$\text{(I-1)} \qquad p.v. = \int_0^\infty qp(q)\, e^{-it}\, dt,$$

of the mine subject to the condition

$$\text{(I-2)} \qquad \int_0^\infty q dt = r$$

where r is the total deposit of the mine. Because no derivative is involved under the integral signs, he suggested instead to maximize

$$\text{(I-3)} \qquad pq(p)\, e^{-it} - \lambda\, q,$$

where λ is a Lagrange multiplier, for every value of t. The first order condition is:

$$\text{(I-4)} \qquad \frac{d}{dq}\,(pq) = p + q\,\frac{d}{dq} = \lambda\, e^{it}.$$

Hotelling did not interpret λ, but it can be seen as the present value of marginal profit, i.e., in case of monopoly, the fundamental principle of the economics of exhaustible resources says that it is the marginal profit that has to be growing, and is expected to grow proportionally like the rate of interest.[2]

There are at least two reasons that theoretical literature is insufficient to answer the question which was raised at the beginning of this chapter: (1) it is not in the form of supply function in order to be tested by the data of the real world and (2) the assumption of constant demand function is far from reality. Accordingly, the remainder of this chapter will be devoted to the following subjects: the definition and derivation of a function which resesembles the supply function of a mine under given conditions and the presentation of the course of price and depletion rates in the case of imperfect competition when the demand for the resource does not necessarily remain the same through time.

THE USER COST FUNCTIONS

Having presented some introductory notes and a review of the theoretical literature, let us consider the behavior of a mine owner under conditions of imperfect competition and known degree of certainty. To present an analytical framework to be tested by the data of the real world, we not only have to make some assumptions about the nature of the problem, but we have to simplify the complex problems of the real world, as well. Accordingly, we may consider the simple case of a mine owner whose objective is to maximize his (properly discounted) intertemporal profit, and not his instantaneous profit.

Assumptions and Definitions

In order to achieve his objective, we assume that the mine owner has obtained the following knowledge and information:

Assumption 1

"The quality of the resource is homogeneous; the total produceable stock of the resource can be estimated and it is accessible to only one firm (or a group of firms which act collectively)." (For the rationale of the assumption and some explanations, see Appendix I-A.)

Definition 1

For each unit of extraction of the resource in a period, t, there will be one unit less remaining for the future periods. The expected discounted profit is foregone because the extraction of this unit is called the "user cost" of the unit. Similarly, each extra unit in the period t will create an extra user cost. The location of the user costs constitute the user cost curve or user cost function.

Assumption 2

As long as the operation of a mine is economical and the expected technology remains more or less the same, the extraction cost has no significant impact on the rate of extraction. The user cost, however, does. (For the rationale of this assumption, see Appendix I-B.)

Assumption 3

The degree of uncertainty can be estimated and shown within the discount coefficient. In other words, "i" in the discount coefficient $(1 + i)^{-t}$ resembles the interest rate and risk coefficient; i.e., we may say that the notation [(Future Profit) $(1 + i)^{-t}$] represents the present value of the future profits in the case of perfect certainty. However, we may call it the expected discounted future profit, in case of known degree of uncertainty. The lower the degree of uncertainty, the closer will "i" be to the interest rate.

Assumption 4

Time is discrete; $t = 0$ denotes the present period and $t = T$ denotes the last period of extraction. T is a decision variable for the firm and is not exogenously determined. Since the quantity of an exhaustible resource and its price may be changing continuously, it would seem the economic analysis of the resource should be in terms of rates of flow at each moment of time, treating the process as continuous through time. This is not an inevitable conclusion, however, and often it is preferable to assume that the variables (price and quantity) change discontinuously so that instead of speaking of a "rate of flow at a point of time" we speak of the "amount," (price, quantity) during a period of time. This gives us the great advantage of being able to construct a step-by-step analysis of the quantity and price changes through time.[15] One of the advantages of this method is that it is a reasonable approximation of reality. The statistics we have of flows in the economy do not relate to time rates but to amounts over a period. We do not know the ex post rate of crude oil imports on 8 a.m. on September 12, but we know the ex post imports of the whole month of September. In other words, our knowledge of much of the economic system is discontinuous, so that an analysis which is discontinuous with regard to time is obviously well suited for application.

Assumption 5

q_t denotes the rate of extraction at time t. For simplicity, we assume away the possibility of storage so that all output q_t is sold during period t.

Assumption 6

The instantaneous demand curve (p_t) facing the firm for each period can be estimated at the present time and is not necessarily the same over time.

Assumption 7

$q_t(p_t)$ is a variable with the following ranges:

$$0 \leqslant q_t(p_t) \leqslant p_t \cdot \frac{dq_t}{dp_t} \quad \text{and} \sum_{t=1}^{T} q_t \leqslant r \quad \text{where } \frac{dq}{dp} \leqslant 0$$

Definition 2

The user cost can be measured by means of three different user cost functions: TOTAL USER COST, AVERAGE USER COST, and MARGINAL USER COST functions. These can be derived from the expected discounted future total, average and marginal profits respectively. The following is a numerical example to illustrate the derivation of the user cost function.

Example 1: Consider a hypothetical mine owner whose objective and information have been explained by the preceding assumptions and the following statistics:

1 - Estimated total proved reserve at time "t" is "r_t".

2 - The last period of extraction is "T".

3 - The discounted coefficient of the future period is $(1 + i)^{-T+t}$.

4 - The estimated demand functions for the present and the future periods are:

$p_o = a_o - b_o q_o$

$p_1 = a_1 - b_1 q_1$

....

$p_t = a_t - b_t q_t$

5 - According to the above information and definitions, the Average User Cost in period t (AUC_t) of this mine is:

$$AUC_t = \frac{A_t - r_t}{B_t} + \frac{1}{B_t} q_t \qquad \text{(I-5)}$$

where:

$$A_t = \sum_{J=1}^{T-t} \left(\frac{a_{t+J}}{b_{t+J}} \right)$$

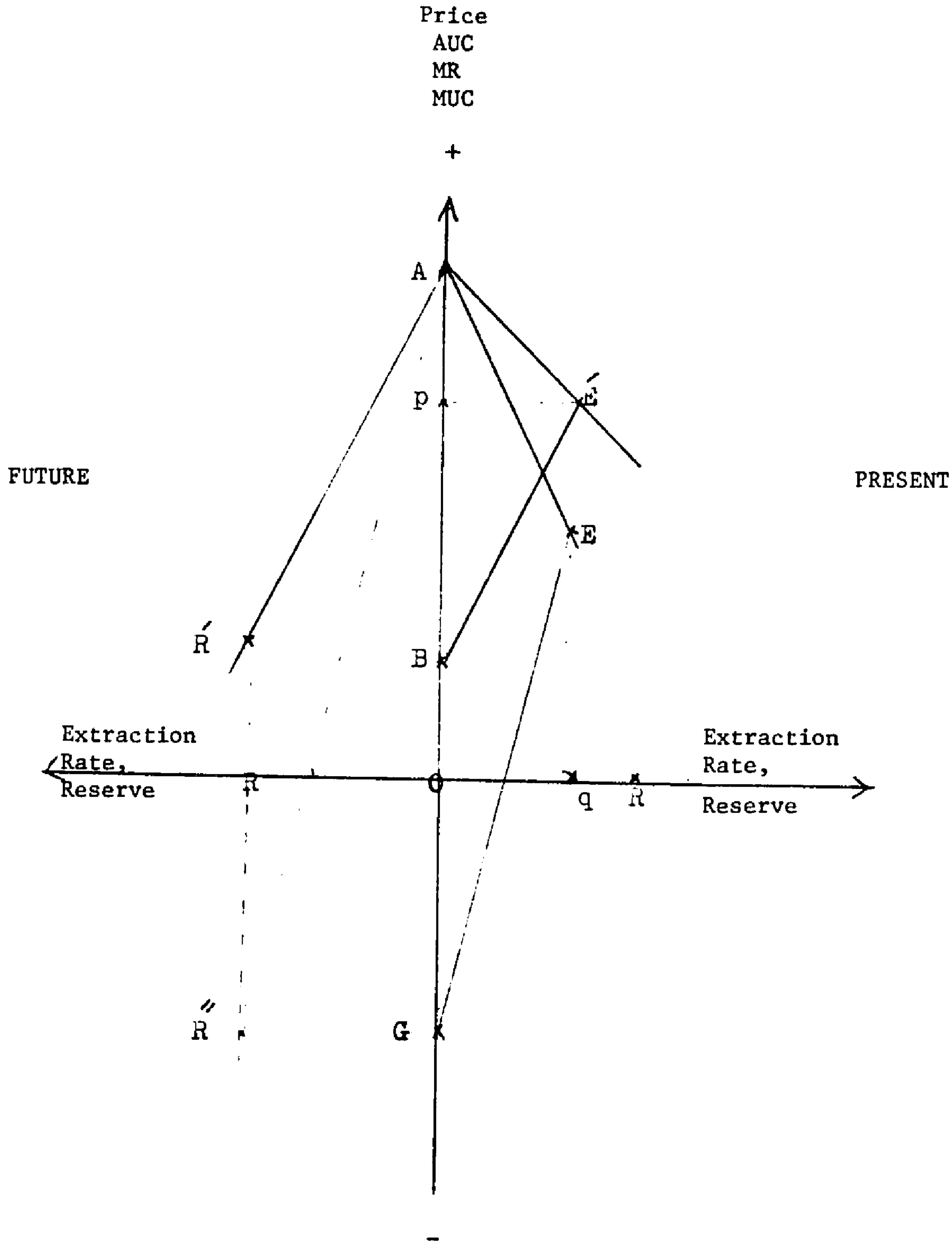

Figure I-5.

Average and marginal user cost functions

Legend Figure I-5

AE' = Demand for the present period ($P_0 = a_0 - b_0q_0$)

AE = Marginal revenue for the present period ($P_0 = a_0 - 2b_0q_0$)

AR' = Demand for the future period.

AR'' = Marginal revenue of the future period

BE' = Average user cost for the present period (AUC_0)

GE = Marginal user cost for the present period (MUC_0)

OR = Total deposits of the reserves

Oq = Rate of extraction during the present period

Op = price for the present period

$b_0 = \frac{AP}{E'P}$

a_0 = OA

$$B_t = \sum_{J=1}^{T-t} \left[\frac{(1+i)^J}{b_{t+J}} \right]$$

Similarly, the marginal user cost for this mine in period t will be:

$$\text{(I-6)} \qquad MUC_t = \frac{A_t - R_t}{B_t} + \frac{2q_t}{B_t}$$

6 - If i = 0 and T = t = 1:

$$AUC_o = a_1 - b_1 r_o + b_1 q_o \quad \text{(see Fig. I-5).}$$

Theorem 1

That rate of production which is the result of the intersection of MR_t with MUC_t is the optimum rate of extraction for the mine owner. It is identical with the rate of extraction which is the result of the intersection of AR_t with AUC_t or TR_t with TUC_t. Using the preceding numerical example, the optimum rate of extraction is:

$$\text{(I-7)} \qquad q_t = \frac{a_t B_t - A_t + R_t}{2 + 2B_t b_t} \qquad \text{(see Fig. I-6).}$$

Application

The application of the model will be presented in Chapter three of this paper. However, a brief summary--to show how this model can be applied to the real world--concludes this part.

Having received some information from the geologist (concerning the quantity of proved reserve: $r = \bar{r}$); from the econometrician (concerning the estimation of demand for the future: $p_t = \hat{a}_t - \hat{b}_t q_t$); and from a banker (concerning the rate of interest: $i = \hat{i}$), the firm

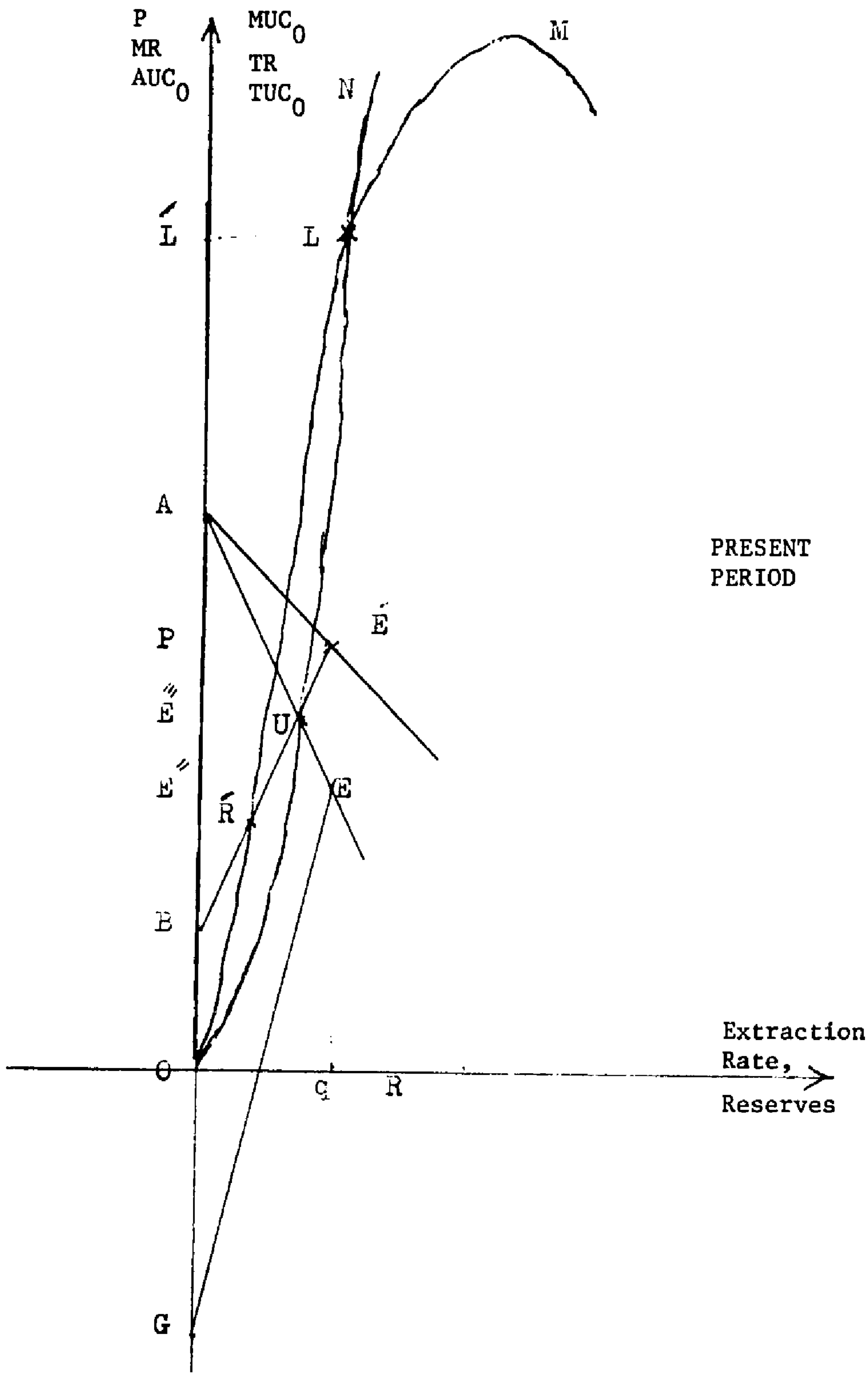

Figure I-6.

User cost functions and optimum rate of extraction

Legend Figure I-6

AE' = Demand curve

AE = Marginal revenue curve

BE' = Average user cost curve

GE = Marginal user cost curve

$OR'LM$ = Total revenue

OULN = Total user cost

OR = The reserve at the beginning of the present period

Oq = The rate of extraction during the present period

qR = The remaining reserve for the future

OP = The price of the resource

$LL' = PE' = Oq$

owner needs some advice from our User Cost Function to tell him: "How much should he put in the market? or "how much should he ask for a unit of the resource today?" Actually, this is not the only time he needs the advice, he may want it later on, too. Whenever he receives good or bad news from the geologist (ΔR), or from the econometrician (ΔD), or from the banker (Δi), he comes to the User Cost Function and asks: "How should I react to this news, do I change p or q?" UC gives the following answers:

(1) $\frac{\partial UC}{\partial R} < 0$

(2) $\frac{\partial UC}{\partial i} < 0$

(3) $\frac{\partial UC}{\partial a_t} \gtrless 0$

(4) $\frac{\partial UC}{\partial b_t} < 0$

The relation (1) simply says: "Whenever the geologist comes with good news of new discoveries, it is good news for consumers, too."

$$\text{If } R\uparrow \rightarrow UC_t\downarrow \rightarrow p_t\downarrow$$

The relation (2) suggests that: "bad news from the banker is a bad thing in the long run; but when it's worse for the owner, it's good for the consumers."

$$\text{If } i\uparrow \rightarrow UC_t\downarrow \rightarrow P_t\downarrow$$

Relation (3) is not new to us: "One of the prices of growth is inflation." For example,

$$\text{If GNP}\uparrow \rightarrow \text{Demand for energy}\uparrow \rightarrow \text{D for oil}\uparrow \rightarrow UC_t\uparrow \rightarrow P_t\uparrow$$

and finally, (4) gives a message which we already know: "New inventions for new energy are a nightmare for the oil owner." For example,

If Production Cost of Nuclear Energy$\downarrow$ $\rightarrow$ D for oil$\downarrow$ $\rightarrow$ $UC_t\downarrow$ $\rightarrow$ $P_t\downarrow$

THE COURSE OF THE PRICE AND DEPLETION RATE:

THE CASE OF MONOPOLY

According to the fundamental principle of the economics of exhaustible resources, in case of perfect competition, the price of the resource increases over time but the rate of consumption decreases over time, i.e.:

(A) $\frac{dq}{dt} < 0$

(B) $\frac{dp}{dt} > 0$

(I-8) $p_t = p_o e^{it}$

In the case of monopoly, the above relations may or may not be correct, i.e.:

(Á) $\frac{dq}{dt} \lesseqgtr 0$

(B́) $\frac{dp}{dt} \gtreqless 0$

(I-9) $p_t \lesseqgtr p_o e^{it}$

Let us see how and when the preceding relations are applicable to monopoly, and why. The necessary condition for the monopolist to maximize his present value of mine profits is to maximize the following function:

(I-10) $$\Pi = p_0q_0 + \frac{p_1q_1}{1+i} + \ldots + \frac{p_Tq_T}{(1+i)^T}$$

subject to:

(I-11) $$\sum_{t=0}^{T} q_t = r$$

To obtain the maximum value for (I-10), subject to the constraint of (I-11) it is enough to maximize (I-12), the augmented objective function.

(I-12) $$Z = p_0q_0 + \frac{p_1q_1}{(1+i)} + \ldots + \frac{p_Tq_T}{(1+i)^T} - \lambda(q_1 + \ldots + q_T - r).$$

The first order condition is:

(I-13) $$p_t + q_t \frac{dp_t}{dq_t} = \lambda(1+i)^t$$

λ, which is a Lagrange multiplier, can be interpreted as the present value of marginal revenue. This conclusion is similar to (I-4); nevertheless, I do not assume constant demand function through time. Relation I-13 indicates, unlike the case of perfect competition, that there is a relationship between the price of the resource in each period and the elasticity of demand in that period. If we re-write equation I-13, we have:

(I-14) $$p_t \left(1 + \frac{q_t}{p_t} \cdot \frac{dp_t}{dq_t}\right) = \lambda(1+i)^t;$$

or

(I-15) $$p_t \left(1 + \frac{1}{\varepsilon}\right) = \lambda(1+i)^t;$$

(where elasticity of demand $\equiv \varepsilon = \frac{dq}{dp} \cdot \frac{p}{q}$)

and finally:

$$(I\text{-}16) \qquad p_t = \frac{\lambda(1+i)^t}{1-\frac{1}{\varepsilon}}$$

To see the importance of equation I-16 and to understand the implication of this conclusion, let us do some exercises. First, let us consider a case where elasticity of demand is the same for each period, i.e.:

$$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \ldots \varepsilon_T = \varepsilon.$$

$$(I\text{-}17) \qquad p_0 = \frac{\lambda}{1-\frac{1}{\varepsilon}}; \qquad p_1 = \frac{\lambda(1+i)}{1-\frac{1}{\varepsilon}};$$

$$p_t = \frac{\lambda(1+i)^t}{1-\frac{1}{\varepsilon}}.$$

We can re-write the above as follows:

$$(I\text{-}18) \qquad p_0 \left(1 - \frac{1}{\varepsilon}\right) = \lambda$$

$$p_t \left(1 - \frac{1}{\varepsilon}\right) = \lambda(1 + i)^t.$$

Or,

$$(I\text{-}19) \qquad \frac{p_0}{p_t} = \frac{1}{(1+i)^t} \rightarrow p_t = p_0 (1 + i)^t$$

Relation I-19 is correct in monopoly if and only if $\varepsilon_1 = \varepsilon_2 \ldots \varepsilon_T = \varepsilon$, while it is true for competition in any case.

Secondly, let us consider a case where the elasticity of demand for the second period is less than for the first period, i.e.:

if $\varepsilon_{t-1} > \varepsilon_t$ then $\frac{1}{\varepsilon_{t-1}} < \frac{1}{\varepsilon_t}$

and $1 - \frac{1}{\varepsilon_{t-1}} > 1 - \frac{1}{\varepsilon_t}$

or $p_t > p_{t-1}(1 + i)$.

This means that if the elasticity of the second year is less than the elasticity of the first year, the increase in the price is more than the rate of interest. In general:

(I-20) If Elasticity of $D_1 = \varepsilon D_2$ then $p_2 = p_1(1 + i)$

(I-21) If $\varepsilon_1 > \varepsilon_2$ then $p_2 > p_1(1 + i)$

(I-22) If $\varepsilon_1 < \varepsilon_2$ then $p_2 < p_1(1 + i)$.

Consequently, in the case of monopoly:

(I-13) $P_t \gtrless p_0(1 + i)^t$.

DUOPOLY & CARTEL

We have seen some outlines of the economics of exhaustible resources under perfect competition, where each firm individually has no influence on the market behavior; and under monopoly, where a single firm is the only producer of the resource. Intermediate between perfect competition and monopoly, and more closely related than either to the real world, is the condition in which there are a few competing producers. There is valuable theoretical literature on "duopoly"[16] which facilitates introducing the problem without presenting unnecessary details.

Externalities and Collusion

According to the neoclassical price theory, as long as the elasticity of demand for a commodity is less than infinity (the demand schedule for the commodity is not perfectly elastic), there will be some "external diseconomies" for the firms producing that commodity. This externality is rooted to the nature of the demand, regardless of the supply which may or may not be affected by externalities. In other words, each firm in the industry continues to increase its production in order to maximize its profit up to the point where $MR_t = MC_t$. By this action, however, each firm introduces some external diseconomies to the other firms in the industry. The result of these diseconomies is the lowering of the industry price to a level where $AR_t = MC_t$ for the industry.

To minimize the external diseconomies, that is to internalize the externalities by means of collusion or cooperation, the firms of the industry may find it beneficial to get together and cooperate with each other against their customers.[17] Therefore, collusion or cooperation which is aimed at minimizing the external diseconomies and consequently maximizes the firm's profits, can be considered a factor of production. The firm will continue to use it, like any other factor of production, until the value of its marginal product exceeds or is at least equal to its marginal costs.

The costs of collusion can be divided into institutional and economic costs. Institutional costs are those laws, regulations, and public opinion which forbid the use of collusion by firms. To measure the economic costs of collusion we should make the distinction between an exhaustible resource and an inexhaustible commodity. If the commodity is inexhaustible then Figures I-7 and I-8 explain the whole story.[18]

If a resource is scarce and exhaustible, we expect a lower economic cost of collusion. With less to lose by a temporary reduction in sales, a seller will be particularly inclined to experiment by raising his price (and/or by reducing the rate of extraction) in the hope that his competitors will also increase their prices (and/or cut back their production). To illustrate this point, we will consider the extreme case of collusion (or cooperation) i.e., the case of cartel, and we will measure the economic costs for a member firm under different assumptions and circumstances.

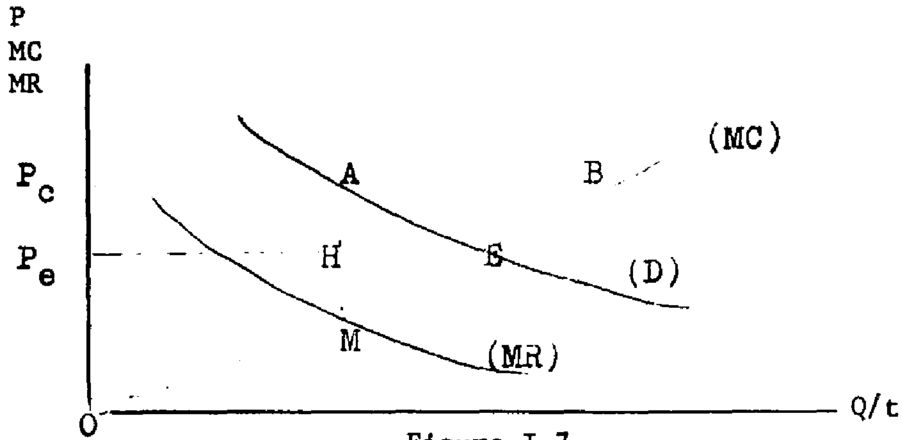

Figure I-7.

Collusion cost: The case of an inexhaustible resource

The supply function has not been affected by externalities. Actual cost of collusion for the firm is EHM, but the benefit of cheating, as the firm sees it, is ABM.[18]

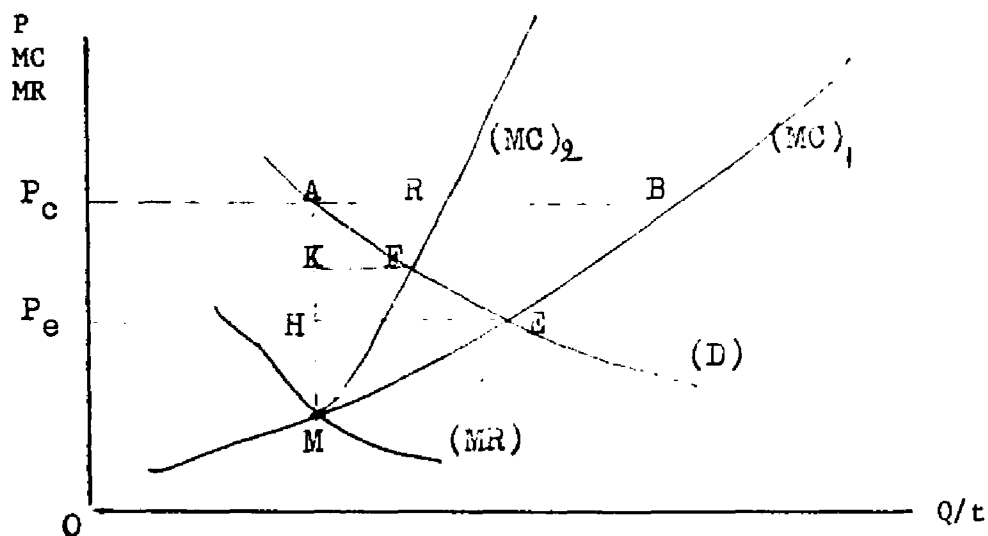

Figure I-8.

Collusion cost: The case of an inexhaustible resource and external diseconomies

The Supply function has been affected by external diseconomies. The actual cost of collusion for the firm is AKF, however, the firm thinks it is AHE. The benefit of cheating is ARM, but the firm thinks it is ABM.[18]

Cartel

(1) A cartel in an exhaustible resource industry may be considered a monopoly, subject to the theory which has been presented in this chapter. In addition, we may have the following information, as well:

"N" is the number of firms in the cartel.

R_i is the total deposits of the mine owner "i".

$\sum_{i=1}^{n} R_i = R_c$ is the total deposits of the cartel.

Q_{it} is the rate of production (quota) of producer i during period t.

$\sum_{i=1}^{n} Q_{it}$ is the rate of production of the cartel at time t.

T is the final period of the extraction; t = 1, 2, 3, ... T.

$\sum_{t=1}^{T} Q_{it} = R_i$ and $\sum_{t=1}^{T} \sum_{i=1}^{n} Q_{it} = R_c$.

(2) The optimum rate of extraction for the cartel, as for a single monopoly, can be determined by the interaction of the demand function for the resource and the average user cost function of the cartel.

(3) The quota for each firm in each period is determined by the cartel such that:

$$\sum_{t=1}^{T} Q_{it} = R_i \quad \text{and} \quad \sum_{t=1}^{T} \sum_{i=1}^{n} Q_{it} = \sum_{i=1}^{n} R_i = R_c$$

(4) as long as the resource market is not in perfect competition, the user cost for the firm is a function of the rate of extraction, even if the operational cost is constant (see Fig. I-9). Whenever there is a cartel for the resource, there are two different user costs: user cost for the cartel and user cost for each individual firm. These user costs may or may not be the same. The following examples illustrate this point:

Example I: If, as the firm sees it, there is certainty, i.e., the cartel will exist in the future; and if "i"--the discount factor--is the same for the cartel and for the firm; and if the price elasticity will remain the same ($p_t = p_0 (1 + i)^t$, then:

THE COST OF COLLUSION FOR THE FIRM IS NEGLIGABLE.

Example II: If, as the member firm sees it, there is uncertainty about the cartel's future and/or the discount rate for the firm is higher than those of the cartel's, then the user cost of the firm is lower than the cartel's (see Fig. I-9). In this case:

THE COLLUSION COST IS SIGNIFICANT.

(5) Conclusion: The preceding cases indicate that collusion cost for an inexhaustible commodity is always significant while for an exhaustible resource it may or may not be significant. In other words, in the case of inexhaustible resource industries, cartels are inherently unstable and sooner or later the economic costs increase and exceed the benefit of collusion, leading to the collapse of the cartel from internal pressures. There is a good possibility, however, that a cartel in an exhaustible resource industry will continue for a long time.

Recently, Osborne[19] has reached the same conclusion through a different method of analysis. He states that the external problem of a cartel, "predicting production by nonmembers," and the internal problems, "locating the contract surface, solving sharing problems, detecting and detering cheating," are inherently insoluble problems for an inexhaustible resource industry, but that these problems, while difficult, are not inherently insoluble for an exhaustible resource industry.

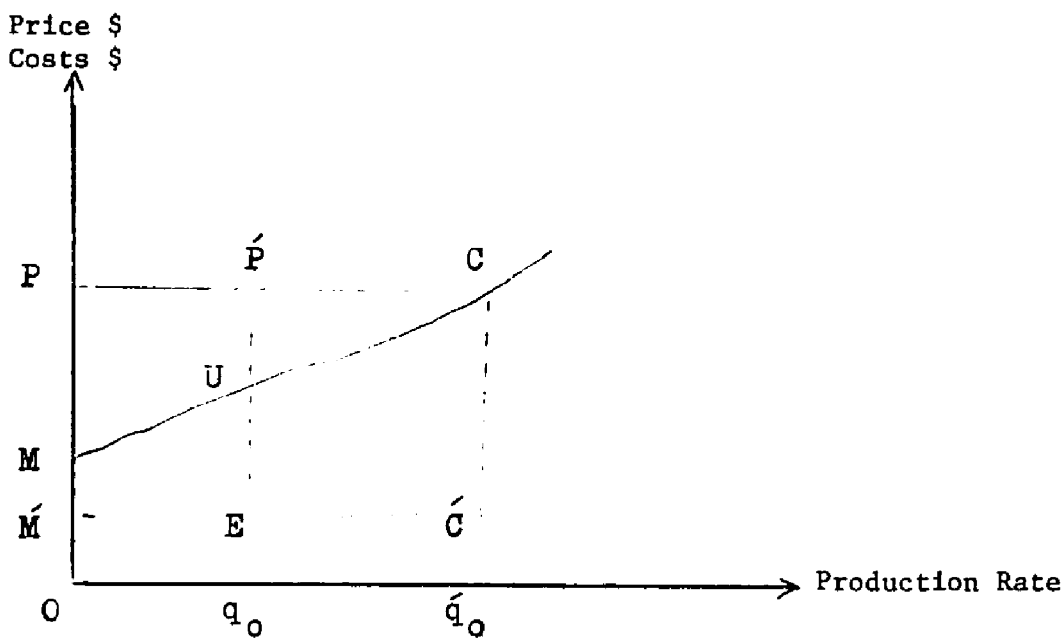

Figure I-9.

Collusion cost: The case of an exhaustible resource

ḾEĆ = Marginal extraction cost

MUC = Marginal user cost

PṔ = Cartel price

Oq_0 = Firm's quota

UṔC (not EṔCĆ) is the cost of collusion

APPENDIX I-A

RATIONALE AND EXPLANATION FOR ASSUMPTION 1

To give an adequte explanation for this assumption, and its rationale, it is best to specify a resource and explain it with data from the real world. What if this resource is crude oil? After all, the empirical work of this paper deals exclusively with international crude oil.

Production of crude oil is the result of a series of activities which we may classify as follows: exploration, development, and well operating. Through "explorations" the oil man finds, if he is lucky, the reservoir, i.e., the oil-in-place. Therefore, Exploration is the process of finding oil deposits. At any given time there are a number of places to look, and the better places are preferred. The higher the oil output desired, the more the costlier prospects must be explored. The second step toward production of oil is development. This process consists of finding the horizontal and vertical limits of the reservoirs in any given field, largely by drilling wells and equipping them for production. Most discoveries are non-commercial; few are developed. Van Dyke's statistics[12] show that only 2% of all new-field wildcats discover a "significant" field, although about 10% produce some oil or gas. The higher the price of oil or gas, the more it pays to develop the poor discoveries.[11] The third and final step is well operating. This process, like its predecessors, is an operation with increasing cost: the greater the output the higher the cost per barrel.

UNDERGROUND STOCK —by exploration—> DEPOSITS OF OIL-IN-PLACE

by development

—> PROVED RESERVE = THE READY SHELF INVENTORY

by well operating

—> CRUDE OIL ON THE GROUND

Figure I-10

The Process of Crude Oil Production

Even neglecting well workovers, fracturing, acidizing, waterflooding, etc., the basic fact about oil and gas production is the production decline curve of the reservoir. The operator needs to know how much more production he can get out of a well or pool before reaching the "economic limits"--the point at which the unit cost of producing more is going to rise above the price. This amount, which is an estimation, is usually called "proved reserve." As in all estimations, different formulas give different results but in practice the results are similar. Because of the importance of the concept of "proved reserve," we present here its definition as has been employed by API.

> The reserves listed as "proved" in this report, as in all previous API reports, are the estimated quantities of crude oil which geological and engineering data demonstrate with reasonable certainty to be recoverable from known reservoirs under existing economic and operating conditions. (13)

For every field for which the cost curve has been estimated, the intersection of the cost function with the price level of the resource determines the "proved reserves." (See Fig. I-11).

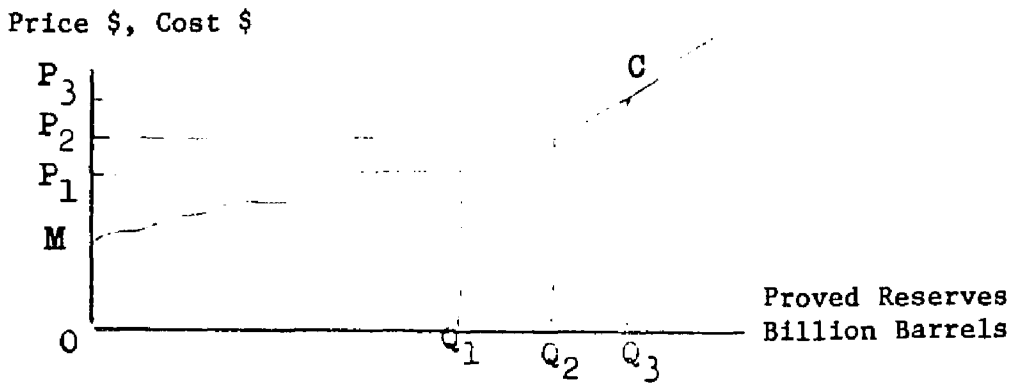

Figure I-11.

The marginal extraction cost and proved reserve

At price P_1 the proved reserve is Q_1 and at P_2 the proved reserve is Q_2 and so on. The following is an example from an oil field in California.

A study by the Department of Oil Properties, City of Long Beach, California shows Wilmington's field has a reserve of 2.3 billion barrels if the price of crude oil is \$2.61. This reserve will be 2.51 billion barrels if the price is \$4.21. If the price goes as high as \$9.21 then the proved reserve of the field will be 2.84 billion barrels.[14] (See Fig. I-12).

So far I have shown that "proved reserve" is a (decision) variable which is a function of the price of the resource: $R_t = f(P_t)$. The reader may ask, "if this is so, why do we assume a fixed stock of the reserve?" The assumption can be defended on two grounds, A and/or B.

How crude price affects Wilmington recovery

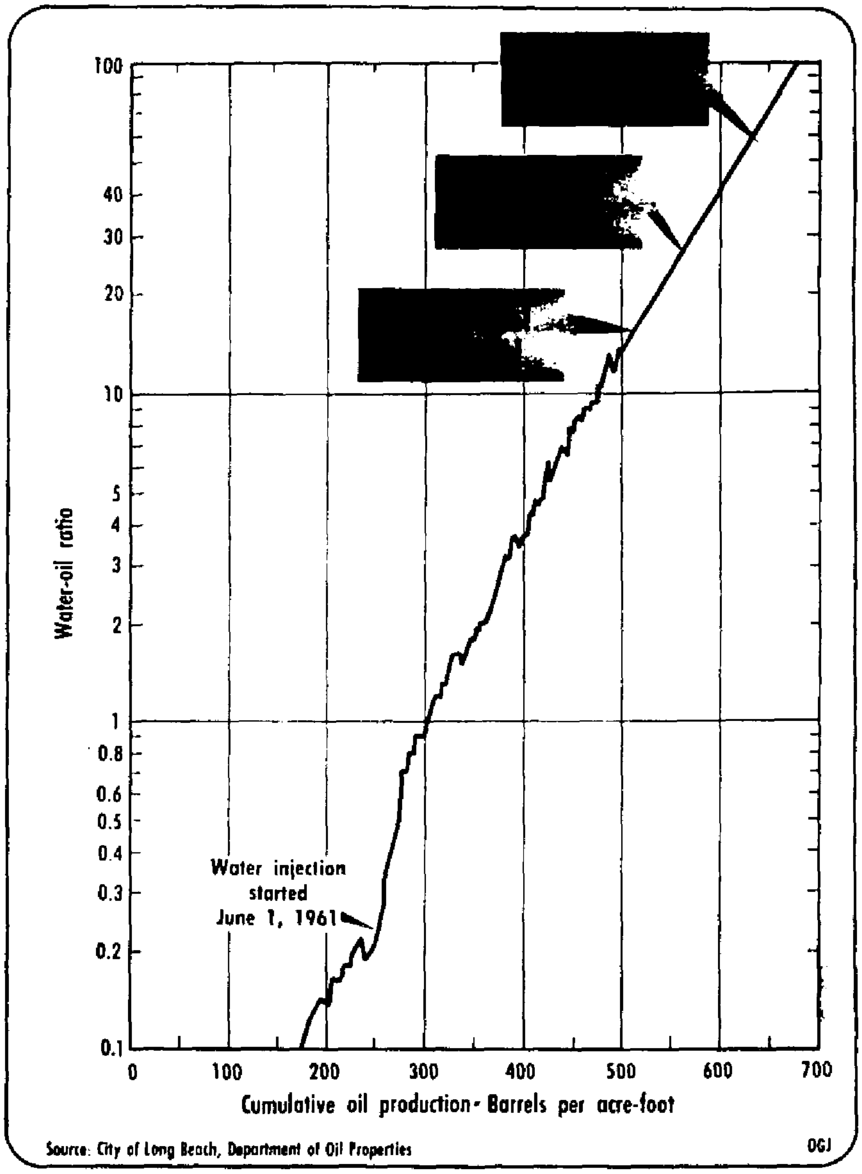

Figure I-12.

(A): The monopolist sums up the demand functions of all the future periods. Assume that the marginal revenue of these overall demand functions, aggregate demand, is as shown in Figure I-13. Under the given conditions (cost and revenue), it is perfectly logical to assume that the amount this monopoly is considering is a "fixed" amount of the resource, $O\bar{Q}$. In other words, the proved reserve which is by nature a variable, can be assumed to be a parameter to this model.

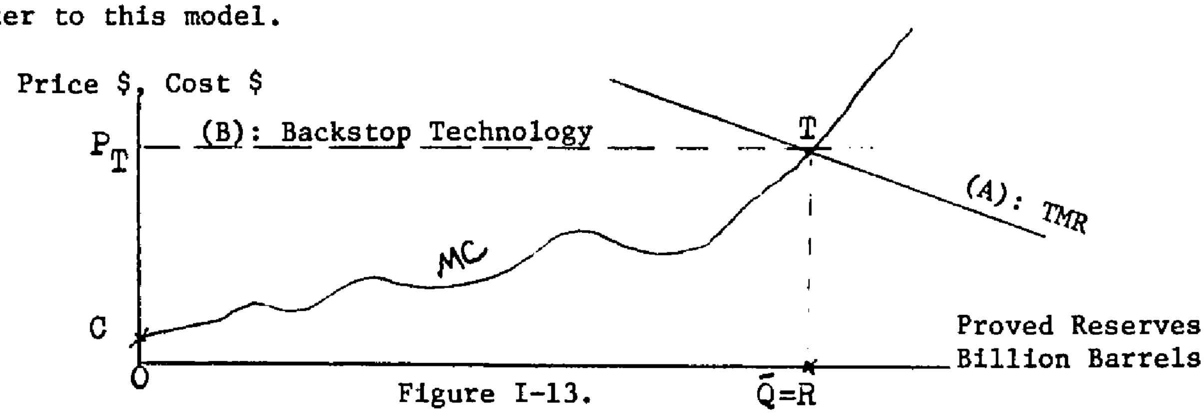

Figure I-13.
Proved reserves and production cost

(B): As we mentioned earlier, the fundamental principle of the economics of exhaustible resources is that the price of the resource is increasing over time (if the market is pure competition) and (if the market is monopoly) it is the "marginal revenue" which increases exponentially. Suppose that somewhere in the background, there is a technology of capable of producing or substituting for the resource at a relatively high cost, but on an effectively inexhaustible resource base. W. D. Nordhaus calls this a "backstop technology" (for the energy industry it might be using U^{238} as a fuel or solar energy).

> Since there is no scarcity rent to grow exponentially, the backstop technology can operate as soon as the market price rises enough to cover its extraction costs (including, of

> course, profit on the capital equipment involved in production). And as soon as that happens, the market price of the resource or its substitute stops rising. The "backstop technology" provides a ceiling for the market price of the natural resource. (2) (See Fig. I-13).

Note

Whenever we use the term "total reserve" we do not mean the literal meaning of the phrase but simply "that portion of the mine which is economical to extract." In other words, regardless of the degree of competition in the market. In Professor Richard Gordon's words:

> The automatic assumption that the pure theory of exhaustion is applicable to natural resource commodities involves a complete misunderstanding. Exhaustion is not necessarily desirable. Just as machines can become obsolete before they wear out, extraction of minerals can become unnecessary before the supply is depleted. Scrap availability might make mining undesirable; solar energy might displace mineral fuels. The pure theory only provides a test of whether exhaustion is profitable. If it were, the theory indicates that we would observe firms sacrificing current profits to increase future supplies. Since mineral industries generally do maximize current profits, the theory actually seems to suggest that exhaustion of minerals is unlikely. Thus, instead of providing rules of conservation policy, the theory suggests that conservationists are concerned about a non-existent problem. (5)

APPENDIX I-B

RATIONALE AND EXPLANATION FOR ASSUMPTION 2

We may find three different ways of justifying that user cost is almost the only cost which alters the decision-making of the mine owner, as in the following:

(A): The price which the mine owner considers is the "scarcity rent" or the "price in the ground"; therefore, the user cost is the only cost for this mine owner.

(B): Geological situation of the mine is such that marginal extraction cost is constant: (1) Conditions of constant costs hold approximately through time. (2) Only if the reserves are fluid, as in a well. Presumably this is why Marshall chose to illustrate his assertion about the absence of diminishing returns in mining with the example of pumping out a reservoir. In this case, as in A, the user cost is the only cost which enters the picture.

(C): Marginal extraction cost for crude oil and most other minerals is actually increasing, not constant. (See Fig. I-13). For example, natural gas dissolved in crude oil exerts pressure that forces the oil to the surface. As production proceeds, the pressure drops and the well produces less. Since the total operating costs of a well are almost constant, unit cost and extrement costs rise, however, if technology is more or less constant; these increasing costs affect the amount of total proved reserves of the mine, not the rate of extraction for a period such as t (if $t < T$). This is so because of the original assumption that the mine owner's objective is maximization of the expected present value of the mine's total profit. In other words, the mine owner wants to maximize Π (present value of total profit) considering the restriction of (Σ qt = r) total reserve:

$$\Pi_0 = p_0\, q_0 - c_0\, q_0$$

(I-23) $$\Pi_1 = (p_1\, q_1 - c_1\, q_1)\ (1 + i)^{-1}$$

$$\Pi t = (p_t\, q_t - c_t\, q_t)\ (1 + i)^{-t}$$

Where $\Pi_t \gtrless 0$ but $\Pi > \sum_{t=0}^{\acute{T}<T} \Pi_t$

(I-24) $$\Pi = (\Pi_0 + \Pi_1 + \Pi_2 \ldots \Pi_t) = \Sigma\, \Pi_t$$

(I-25) $$\Pi = \sum_{t=0}^{T} \frac{p_t q_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{c_t q_t}{(1+i)^t}$$

(I-26) $$\sum_{t=0}^{T} (c_t q_t) = s$$

S is almost constant because it is the area under the curve of OCTR (Fig. I-13). Accordingly, we may expect--under normal conditions--to get almost the same results if we maximize $\acute{\Pi}$ in relation I-27 subject to the constraint of total proved reserve or Π in relation I-25.

(I-27) $$\acute{\Pi} = (q_0 q_0) + \frac{p_1 q_1}{1+i} + \ldots + \frac{p_t q_t}{(1+i)^t} - \lambda\ (q_0 + q_1 + \ldots + q_t - r)$$

which means extraction cost does not affect the rate of extraction in Period t.

FOOTNOTES

[1]H. Hotelling, "The Economics of Exhaustible Resources," Journal of Political Economy 39 (April 1931):137-197.

[2]R. M. Solow, "The Economics of Resources or the Resources of Economics," The American Economic Review (May 1974):1-14.

[3]See the References for Heal (1974), Solow (1974), etc.

[4]L. C. Gray, "Rent Under the Assumption of Exhaustibility," Quarterly Journal of Economics 28 (May 1914):66-89.

[5]R. L. Gordon, "A Reinterpretation of the Pure Theory of Exhaustion," Journal of Political Economy (1967):274-285.

[6]See Footnote 2 and R. Solow, "Intergenerational Equity and Exhaustible Resources," Review of Economic Studies (1974):29-46.

[7]O. C. Herfindahl, "Some Fundamentals of Mineral Economics," Land Economics (May 1955):131-138.

[8]A. T. Scott, "The Theory of the Mine Under Conditions of Certainty," in Extractive Resources and Taxation, ed. M. Gaffney (Madison: The University of Wisconsin Press, 1967), pp. 25-62.

[9]Hicks, Value and Capital, p. 15.

[10]S. D. Krasner, "Structuring International Raw Materials Markets," Unpublished paper, 1975.

[11]M. A. Adelman, The World Petroleum Market.

[12]L. H. Van Dyke, "North American Drilling Activity in 1967," American Association of Petroleum Geologists Bulletin (1968):904-81. See also footnote 11.

[13]Annual Reports of the American Petroleum Institute.

[14]Oil and Gas Journal (January 20 1975): 31-35.

[15] W. T. Baumal, Economic Dynamics, 3d ed., (New York: Macmillan Company, 1969).

[16] Joan Robinson, The Economics of Imperfect Competition; Chamberlin, The Theory of Monopolistic Competition, etc.

[17] Adam Smith, The Wealth of Nations

[18] See especially, M. Friedman, Price Theory and G. Becker, Economic Theory.

[19] D. K. Osborne, "Cartel Problems," American Economic Review (December 1976):835-54.

CHAPTER 2

A BRIEF EVALUATION OF THE ECONOMIC FORCES OF THE INTERNATIONAL OIL INDUSTRY AND THEIR CHANGES OVER TIME

I. A BRIEF HISTORY OF THE INDUSTRY'S STRUCTURE

No commodity has been, and is, more in the news and more controversial than oil. It all started on its very day of birth in 1859, when Drake drilled the first well near Titusville, Pennsylvania, to extract oil: a preacher in the town condemned the project as being immoral because, he said, the oil was needed down there to feed the fires of hell![1] The criticisms in somewhat fancier words have been continuous since that time by different people and for various purposes. On the other hand, there is no shortage of admiration and rewards either. The following is just one among many:

"OIL" a number one commodity in international trade

Oil!
Beneficent oil,
Mankind's most precious treasure in the soil!
Oil!
Disgusting oil,
Father of blood and sweat and tears and toil!
Oil, you have made this Puny race
Masters of time and Lords of space,
Have opened vast horizons for the poor,
And brought the city to the cottage door,
Or rather (which is not so good)
The cottage door to Hollywood.
Oil, you have made the mountains and the seas

Mean less than barbed wire fences mean to bees.

Methinks I see this writing in the sky:

'Those who by oil have lived by oil shall die!

- Sir Alan Herbert

In spite of the masses of miscellaneous information on the international oil industry--probably more than any other industry in the world--little has been written or reported on the techniques or theory of the pricing of crude oil.[2] Moreover, the economics of oil may be viewed from the varying, and often opposing, standpoints of the producing countries, the operating companies or the consumers. We have seen some outlines of the economics of exhaustible resources under different market structures in Chapter I. The goal of this chapter is an explanation of why the particular behavior observed (price increase of crude oil in 1973-74) emerges from the very dynamics of the industry. This is a partial equilibrium analysis and is far from being detailed; nevertheless, it investigates the forces affecting the market behavior of the industry.

A. The Price Increase of 1973-74

Although talking of oil and oil in the news is not new, nevertheless, this time it is not simply the news but what everyone feels and thinks about paying for it. The price of crude oil has increased more than two hundred percent almost overnight. What were the reasons behind it? Since that time, not more than three years ago, tens of books, hundreds of articles and innumerable lectures and seminars have been devoted to answering this question, and still there is no satisfactory explanation of it. This study hopes to shed some light on this question, not only what happened in the past but what may happen in the future.

The price increase of 1973 was almost coincidental with two other international events: the Arab-Israeli war and the oil embargo. The war and probably the embargo had been caused mostly by non-economic factors. How about the price increase? The chances are that the answer is affirmative, especially since many non-economists (and some economists, too) have found direct correlations among the three events: war, embargo, and the price increase.

It was a war that some Arabs participated in; it was an embargo that some Arabs imposed; and finally, it was a price hike which some Arabs benefited from. Therefore, these events are related to one another since, if there had been no war, there would have been no embargo and no price hike! The logical conclusion of that line of reasoning is: "It was a war between Semite peoples (Arabs and Israelis), but the rest of the world paid the price."

That kind of logic reminds me of the following story: There was once a cholera epidemic in Old Russia. The government, in an effort to stem the disease, sent doctors to the worst-affected areas. The peasants of the province discussed the situation and observed a high correlation between the numbers of doctors in a given area and the incidence of cholera in that area. Relying on these hard facts, they rose and murdered the doctors.[3]

The hypothesis of this paper disputes the preceding reasoning. In other words, the hyposthesis of this paper is: Even if we accept the assumption that international oil industry is not (and has not been) perfect competition, nevertheless, it is the demand and the supply which are (and were) mostly responsible for the price increase--not war nor politics. The monopoly power in the oil industry in the long run is limited because, in the long run, the elasticity of substitution moves toward infinity ($\sigma \rightarrow \infty$).

To systemize the explanation of the causes of the price increase, we will present a short history of the crude oil prices, followed by a brief summary of the structure of the international oil industry and its changes over time. Then we will analyze the elements which determine the supply function and the demand function; each will be followed by its changes over time.

B. The Price Stability of Crude Oil

Before the 1930's, oil was one of the least stable commodities. When Drake "tapped the mine," he was under contract to pay a royalty of ten cents a gallon on all crude oil produced; in too short a time Pennsylvania crude was selling for ten cents a barrel. Periods of "feast or famine" have been all too common. See the following table:

Table 1: Monthly Average Price Per Barrel of Crude Oil at Well

	1860	1861	1862	1863	1864	1865
January	$18.25	1.00	0.10	2.25	4.00	8.25
February	18.00	1.00	.15	2.50	4.37	7.50
March	12.62	1.00	.22	2.62	5.50	6.00
April	11.00	.622	.50	2.87	6.56	6.00
May	10.00	.50	.85	2.87	6.87	7.37

Source: Stanley Clark: The Oil Century

At the turn of the century, Spindletop came in with a roar and the price of oil fell to three cents a barrel. A few years later, the gushing abundance of the Cushing field in Oklahoma in 1915 forced prices downward to twenty-three cents. Two years after that prices went up to four dollars a barrel.[4]

But since the second World War, petroleum has been considered one of the most stable commodities (see Table 2).

Table 2: Price Stability 1949 - 1974

	Commodity	Average Annual Percentage Change in Price
Very Stable	Banana	4.4
	Petroleum	4.6
	Wheat	5.6
	Sugar	6.8
Unstable	Coconut Oil	20.1
	Rubber	21.1
	Cocoa	26.5

(In each case the single highest figure has been dropped.)
Source: <u>Structuring International Raw Materials Markets</u>, by Stephen D. Krasner

Why have petroleum prices, so unstable in the past, become so stable now?[5] The answer may be found in the structure of the industry itself and its changes over time, i.e., studying the price changes of a commodity is the first step in identifying the structure of the industry. The following is a brief summary of the structure of the international oil industry and the changes which have taken place

C. The Forces in the Industry

Oil is the preeminent commodity in international trade by any standard, whether economic, political or strategic. Key elements in this trade are (1) the export-import relationships among countries and (2) the dominant role of a handful of international companies.[6]

Any change in the price or quantity of oil is "news" and will affect many nations, directly or indirectly. Finally, the international oil industry has become the most complex, sophisticated and controversial economic phenomenon of our time. Despite such a complex interplay of political and economic forces, the price structure in the world petroleum market can be used as a benchmark of economic theory. The first step in the study of the price mechanism is to investigate the structure of the industry itself.

The petroleum industry is a phenomenon in two respects. First, most of the world's oil reserves are located in a few countries and are refined and/or marketed by a handful of companies which are some of the biggest corporations in the capitalist world. Second, oil men live, more than any other industry, in the future, making decisions on the basis of expected rather than currently existing variables. The first aspect of the industry's structure requires inspection for the degree to which it engages in competition and its changes over time. Implicit in the second aspect is the fact that a static method of analysis is not adequate to the study of the behavior of this market. Therefore, a brief exposition of the trend and direction of competition is necessary for an understanding of the structure of the industry.

In 1928 oil men took steps to translate their concern about price instability on international oil markets into a program of action. Sir John Cadman of Anglo-Persian, Sir Henri Deterding of Royal Dutch-Shell, and Walter C. Teagle of New Jersey Standard Oil--the big three--projected a plan designed to supplement the control program and bring stability to the world oil markets. This agreement later was called the "AS-IF Agreement,"[7] and opened a new era for the international oil industry.

Around 1950 the major companies, the seven sisters, controlled nearly 90 percent of oil production outside the United States and the Soviet bloc and almost eighty percent of refining capacity. In addition, they owned or chartered two-thirds of the world's tanker fleet.[8] They also controlled a large proportion of the markets in the consuming countries.

Since the Second World War the number of firms operating in "the industry" has increased. The first economic consequence of this was that the cost of collusion by "the big Seven" rose as their share of the market declined. Competition, though far from perfect, resulted not only among the newcomers but among the majors as well. The second consequence was the emergence of a new economic power in the industry which has been growing steadily ever since, i.e., the power of the oil-producing countries to determine the price and the rate of extraction.

Iran, the pioneer of the industrialization of the oil resources of the Middle East, sought to increase her portion of oil profits by asking the British Petroleum Company to revise its method of revenue-sharing. The B.P. refused. Thus began the dispute between Iran and British Petroleum which continued until 1951 when Iran decided to fully compensate British Petroleum and nationalize her oil. She then faced not only the opposition of British Petroleum but that of the whole international oil cartel. The cartel's boycott of Iran's oil was successful and Iran struggled with enormous internal economic and political problems. Finally, in August of 1953, the administration of Dr. Mossadegh collapsed and the new administration was forced to accept British Petroleum's terms. The result of the cartel's victory was a bonus of 50% net profit on Iranian oil for all the international oil companies (the "seven sisters" and some independents) who participated in the boycott.[9]

Iran's experience proved a crucial point to the oil-producing countries: either they could continue to allow foreign companies to exploit their resources and collect their royalties or they could act collectively on their own interest. This latter line of thinking gave birth to OPEC which began a new era in the oil industry.

From the time of its inception, OPEC was torn between two conflicting desires within each of its member nations:

(1) Their desire to increase their revenues in order to industrialize. That involved asking foreign companies to increase oil production and made competition with fellow producer countries in OPEC inevitable.

(2) Their desire to trust and cooperate with one another and thereby bargain collectively with the international companies.

The events of the 1960's favored the second method of opportunity and, relatively, diminished the power of the International Oil Companies.[10] By the early 1970's, the international oil industry underwent a revolution which was marked by four important changes:

(1) Strategic crude oil pricing and production decisions were taken from the multinational oil companies by OPEC;

(2) From 1973-1974 the international price of crude oil increased more than 300%.

(3) Some cut-back in oil production took place;

(4) Nationalization of oil reserves was accomplished by most of the OPEC members.[8]

II. THE ELEMENTS OF DEMAND FOR PETROLEUM

The products and uses of petroleum are numerous, but its major function is as a source of energy. This means the demand for petroleum is a demand derived from the need for energy. On the other hand, energy itself is a factor of production and the demand for it is itself a derived demand. To derive the demand function for petroleum products in general and crude oil in particular, we should consider the facts that, at this level of technology the only use of oil is to produce energy, but, oil is not the only source of energy.

The crucial question for obtaining the demand function for oil, as well as any other demand function, is: what determines the shape of the curve? There are three elements which determine the shape of the demand function for oil, they are: (1) the demand function for energy, (2) the supply functions of all other sources of energy, and (3) the elasticity of substitution between oil and other sources of energy.

The elasticity of substitition is an economic variable which may be any number from zero to infinity, depending on the length of the period of analysis. If a short period is chosen, say six months, then there is a good chance that σ, the elasticity of substitution, will be a small number close to zero. On the other hand, if a long period is chosen, say ten years, then σ will be a large number close to infinity. Therefore, σ may be considered as being equal to zero, infinity or a number between zero or infinity. If $\sigma=0$ it means no substitution at all and if $\sigma = \infty$ it means perfect substitution. If $\sigma = \infty$, i.e., all the economic causes and their effects take place in the same period, and if the estimated demand function for energy and supply function of all other sources of energy are given, then it is possible to derive the demand function for petroleum. For example, if demand for energy is:

$$(1) \quad p_e = a - bq_e$$

and if the supply for all other sources of energy is:

$$(2) \quad p_s = c + dq_s$$

then the consumption of energy without using oil will be:

$$(3) \quad q = \frac{a - c}{b + d}$$

where the unit price of energy is:

$$(4) \quad p = \frac{ad + bc}{b + d}$$

Consequently, the demand for oil which can be used only as a source of energy is:

$$(5) \quad p_{oil} = \left(\frac{ad + bc}{b + d} \right) - \left[\frac{b(ad - dc)}{(b + d)(a - c)} \right] q_{oil} \ .$$

(See Figure II-1.)

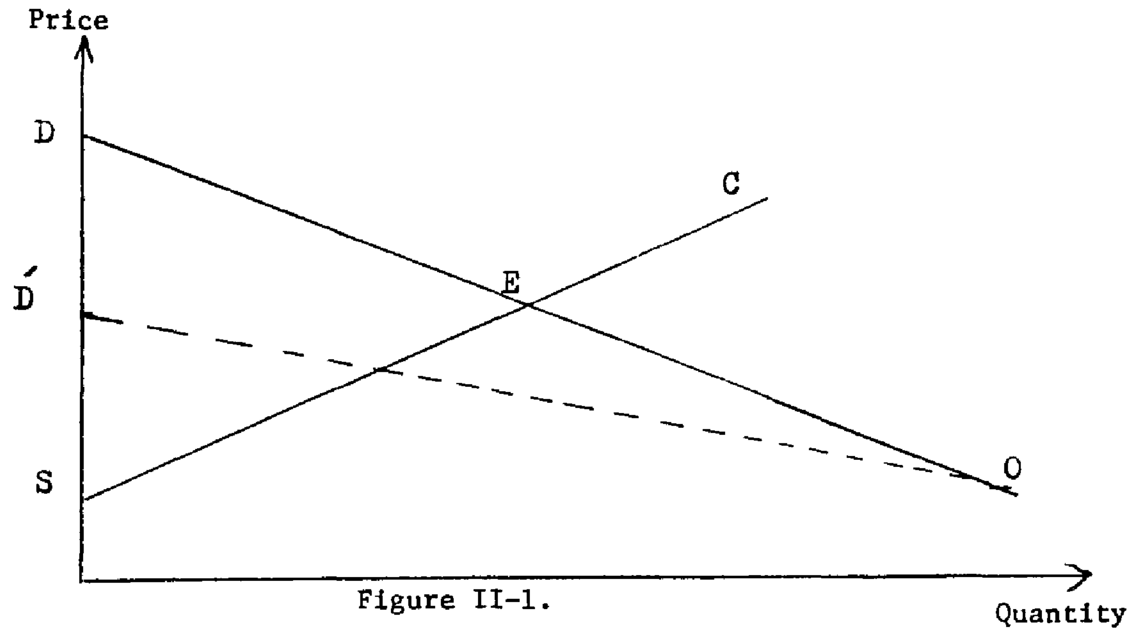

Figure II-1.

Derived demand for oil

DE = Demand for energy

SC = Supply of all other sources of energy

DO = Demand for oil

A. The Production of Energy

Energy has been considered the fourth factor of production, after labor, land and capital. Economic activity has always required relatively large amounts of energy. It has been estimated that until the Industrial Revolution, some 80 to 85 percent of total energy was provided by plants, animals and humans. The introduction of the steam engine in the eighteenth century opened a new chapter for energy and was the turning point of a new life style for human beings. Although the early engines were grossly inefficient, they could produce as much as 100 horse power. The aggregate horsepower of steam engines in Britain in 1800 may have been about 10,000; by 1840 the figure was over 600,000 and by 1900 over 14,000,000. Corresponding estimates for the whole world are about 1,650,000 horsepower in 1840 and over 70,000,000 in 1900.[10] The twentieth century opened another era in the economic development of the world and, consequently, revolutionized the production and consumption of energy.

In every country, growth in the aggregate demand for energy bears a close relationship to growth of the economy in general. But, while there is a broad parallelism between economic growth and energy growth, it is important to pin down this relationship as precisely as possible. Both cross-sectional and times series regression analyses show a high correlation between per capita income and energy consumption.[11] For the world as a whole in 1950 to 1965, the Energy-GNP Elasticity Coefficient was 1.06, i.e., a one percent increase in real gross national product was accompanied by a 1.06 percent increase in energy consumption.[10]

In other words, the long-term growth of total energy use in the world as a whole or in each country individually has been closely parallel to the world's economic expansion, even though the two trends have not always proceeded in lockstep. For example, from 1900 to 1970 the rate of GNP growth for the U.S.A. is 3.3 percent but the yearly growth rate for aggregate consumption of primary energy resources is slightly lower, i.e., 3.2 percent. On a per capita basis, the long-term growth rate of energy comes to 1.7 percent per annum, while the GNP per capita is 1.8 percent. For the more recent fifty year period, from 1920 to 1970, a wider gap in growth rates prevailed: energy consumption grew at the average annual rate of 2.5 percent; GNP at 3.3 percent. The respective per capita figures were 1.2 percent and 2 percent.[11]

Table 3

World Energy Consumption (Million Metric Tons Coal Equivalent)

	1925	1938	1950	1960	1965	1966	1967	1968	1969	1970	1971	1972	1973
Solid Fuels	1230	1292	1593	1999	2268	2310	2207	2274	2326	2394	2392	2430	2486
Liquid Fuel	197	378	722	1499	2001	2172	2329	2543	2736	3002	3169	3340	3657
Natural Gas	48	100	252	613	931	1014	1092	1189	1302	1436	1529	1616	1695
Hydro-Electricity	10	23	43	86	117	128	132	138	148	157	167	179	189
Total	1485	1793	2610	4197	5318	5623	5759	6144	6512	6989	7257	7566	8027

Source: Darmstadter, J., Energy in the World Economy, (Baltimore: The Johns Hopkins University Press, 1971).
United Nations Statistical Yearbooks.

The major source of energy has changed over time. Coincident with the Industrial Revolution in Britain was the displacement of wood by coal as the main fuel. In Britain, about 10 million tons were mined in 1800, or 1.1 tons per head of population. By 1860, the total had risen to 80 million tons, or 3.5 per head. And, by 1910, to 264 million, or 6.1 tons per head. Corresponding figures for the world were about 15 million, 132 million and 1,057 million tons. At the outbreak of the First World War, coal constituted over 90% of the world's commercial sources of energy.[10]

Compared to coal, petroleum was a latecomer, and assumed importance as a source of energy only after World War I. Commercial production started in the 1850's, but total world output only reached the 7 million barrels level by 1972, and the 766 million barrels mark was not passed until 1921. Correspondingly, its share of the world production of commercial energy sources rose to 6 percent in 1913 and to 10 percent shortly after the First World War.

Development since 1925 is shown in Table 3. Over the whole period, total energy consumption rose at a compound rate of 3.4 percent a year. A breakdown into subperiods shows wide fluctuations, the rate for 1925 to 1950 being only 2.3 percent and that for 1950 to 1968 about 5 percent.

. Demand Elasticity

It was pointed out that the economic studies show a high correlation between the consumption of energy and the real GNP of the world (and in each country). But, unfortunately, our knowledge of demand elasticity of energy is limited. According to some empirical works, in the long run, energy is a substitute vis-a-vis all other inputs; therefore, there are no offsetting complementaries (such as between capital and energy in the short run) to diminish the impact of rising energy prices on the demand for energy. The demand elasticity, as we expect it, is different from one country to another and is less than one (i.e., demand is inelastic) but nontrivial. The result of an empirical study by Griffin and Gregory[11] has been shown in Table 4. As we see in the table, the first column shows the energy own-price elasticity (E_{EE}) which is negative, of course, and significantly different from zero. E_{EK} is the cross elasticity between energy and capital and E_{EL} is the cross elasticity between energy and labor.

Table 4: Own and Cross-Price Elasticities

Country	E_{EE}	E_{EK}	E_{EL}
France	-.80	.27	.52
W. Germany	-.80	.40	.40
Italy	-.79	.33	.45
U.K.	-.80	.27	.53
U.S.	-.79	.15	.64

Source: J. Griffin and P. Gregory[11]

Even if the demand elasticity of energy is inelastic, the demand elasticity of petroleum as a source of energy, in the long run, is elastic. This is because of the existence of substitutes and a high degree of elasticity of substitution that we observe and expect between the sources of energy.

III. THE ELEMENTS OF THE SUPPLY OF OIL

The first step in analyzing and measuring the cost of production for oil is to determine whether or not oil is subject to the economics of exhaustible resources. In other words, there are two approaches to measuring the cost: accepting or rejecting the existence of "scarcity rent" for the resource. If there is scarcity rent, the resource can be classified as an exhaustible resource and its present quasi supply function is determined by its user cost. However, if there is no scarcity rent for the resource, the supply function of the resource is determined by its production cost and monopoly power, if any.

The hypothesis of this paper accepts the existence of the scarcity rent and the statistical inferences will be presented in Chapter 3. Thus, the present quasi supply schedule for oil is its marginal user cost function. On the other hand, user cost depends on the proved reserves and the expected discounted future prices (e.d.f.p.). A brief explanation and description of the proved reserves will be followed by a brief description of e.d.f.p. and its changes over time.

A. Proved Reserves (R)

The total deposits of the world's petroleum can be classified into two categories: (1) known reserves and (2) unknown reserves (or speculative reserves). However, known reserves have also been classified into two types: proved reserves and probable reserves (or oil-in-the-place),(see figure II-2).

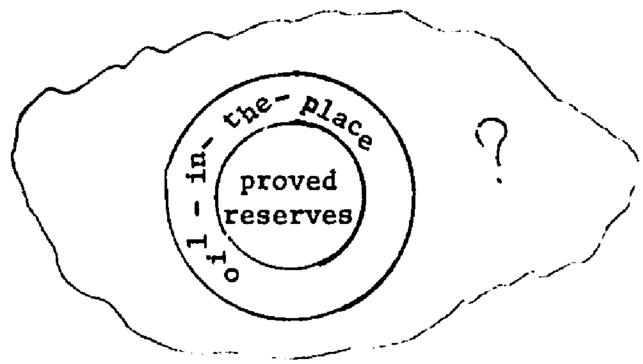

Figure II-2: Probable, Possible and Proved Reserves

The unknown (speculative) reserves are those deposits in the earth whose location and size are not known; their size is a random variable which can be any positive number, and may be too large or too small. The expected size of this reserve may vary from one period to another, depending on many factors such as geological reports, success or failure of big discoveries, etc. For instance, the expectation of large reserves was very high during the 1950's because there was good news of oil discoveries each year; it is not as high in the 1970's because there have been no big discoveries nor encouraging words from geologists. Since there is no reliable information concerning this type of reserve, we cannot include these speculative reserves in our analysis.

Probable (recoverable, or oil-in-the-place) reserves are deposits whose location is already known and whose size can be estimated, but for which there is no estimation of cost (or the cost is so high that it is not economical to produce the deposit). For example, according to API the total recoverable crude oil in the earth in 1974 was estimated at 2685 billion barrels, but there is no estimation of the cost or the cost is so high that most portions of the field contain deposits which are not economical to extract.

Proved reserves, R, are that portion of oil-in-the-place for which (1) the estimated costs are available and (2) the operation of the field is economical. It was pointed out that R is an economic variable whose quantity may change over time. The changes may be caused by one or more of the following:

(1) revision of the old estimation due to technological or economic changes,

(2) new oil field discovery,

(3) extraction during the period.

To study the trend of R and its changes over time it is extremely important to make the distinction between the causes of its increase, i.e., the increase of R due to the revision of the old estimation or due to new discoveries (from the inner circle in Figure II-2 or from the outer circle.) To more easily distinguish between these two different sources of increase in R, it is better to back date any increase in the proved reserves of a field (caused by improvement of technology and/or a price increase) to the year of discovery of the field.

During the last few years when oil was, is, in the news, many good economists (as well as non-economists) have failed to make the proper distinction between the published proved reserves and backdated proved reserves and have been (and are) confused. They saw that R was increasing over time as fast as production and that, therefore, there was no scarcity involved. Their logical conclusion was: "The price must decline toward the lowest production cost." The following is one among many examples of this line of reasoning:

Table 5

Published Proved Reserves (R), Production (Q), and R/Q for Selected Countries

(Billion Barrels)

	Iran			Saudi Arabia			Venezuela			U.S.A.		
	R	Q	R/Q	R	Q	R/Q	R	Q	R/Q	R	Q	R/Q
1938	-	0.08	-	-	-	-	-	0.19	-	17.0	1.26	13.5
1948	-	0.19	-	-	-	-	-	0.49	-	27.0	2.19	12.3
1953	15.0	0.00	-	28.0	-	-	-	0.95	-	29.0	2.4	12.0
1958	-	0.29	-	-	0.38	-	-	-	-	37.0	2.74	13.5
1963	37.0	0.53	70.0	60.0	0.65	92.3	17.0	1.12	15.2	31.0	2.75	11.3
1964	38.0	0.61	62.3	60.0	0.69	87.0	17.0	1.24	13.7	31.0	2.74	11.3
1965	40.0	0.68	59.0	60.0	0.8	75.0	17.2	1.27	13.5	31.3	2.84	11.0
1966	44.0	0.77	57.2	66.0	0.95	70.0	17.4	1.24	14.0	31.4	3.02	10.4
1967	44.0	0.94	47.0	75.0	1.02	73.5	17.0	1.3	13.0	31.4	3.21	9.8
1968	54.0	1.04	52.0	77.0	1.11	69.4	15.5	1.33	11.7	30.7	3.31	9.3
1969	55.0	1.23	44.7	140.0	1.17	120.0	14.7	1.32	11.1	29.6	3.36	8.8
1970	70.0	1.90	36.8	128.0	1.38	93.0	14.0	1.37	10.2	39.0	3.51	11.1
1971	55.0	1.70	32.4	145.0	1.48	98.0	13.9	1.32	10.5	45.0	3.45	13.0
1972	65.0	1.84	35.3	138.0	2.09	66.0	13.7	1.20	11.4	43.0	3.44	12.5
1973	65.0	2.15	30.2	150.0	2.68	56.0	15.0	1.26	12.0	41.0	3.35	12.9
1974	66.0	2.22	30.0	164.0	3.0	55.0	15.0	1.11	13.5	40.0	3.26	12.3
1975	64.0	2.35	27.5	148.0	2.65	57.8	17.7	0.88	20.0	33.0	3.05	10.8
1976	63.0	2.30	27.4	110.0	3.13	35.1	15.3	0.84	18.2	31.3	2.96	10.6

Source: See footnote 18.

Table 6

Published Proved Reserves (R), Production (Q), and R/Q for the World, Middle East, and Africa

(Billion Barrels)

	World			Middle East			Africa		
	R	Q	R/Q	R	Q	R/Q	R	Q	R/Q
1938	30.0	2.0	15.0	3.0	0.12	25.0	0.0	0.0	-
1948	77.0	3.6	21.4	33.0	0.42	78.0	0.0	0.001	-
1953	135.0	4.7	28.7	78.0	-	-	0.0	0.003	-
1958	279.0	6.9	40.4	174.0	1.54	113.0	4.0	0.03	-
1963	326.0	9.5	34.3	207.0	-	-	16.3	-	-
1964	338.0	10.77	31.4	212.0	2.78	76.0	19.3	-	-
1965	348.0	11.0	31.6	215.0	3.04	70.0	23.0	0.81	2.84
1966	381.0	12.0	31.8	236.0	3.4	77.7	32.3	1.03	31.4
1967	407.0	12.8	31.8	249.0	3.66	68.0	42.3	1.14	37.1
1968	454.0	14.0	32.4	270.0	4.12	65.5	44.5	1.46	30.5
1969	530.0	15.2	34.8	333.0	4.54	73.3	54.6	1.85	29.6
1970	611.0	16.7	36.5	344.0	5.10	67.4	74.6	2.22	33.6
1971	641.0	17.6	36.4	366.0	5.98	61.2	98.0	2.06	47.5
1972	672.0	18.5	36.3	355.0	6.61	53.7	106.0	2.08	51.0
1973	634.0	20.3	31.2	349.0	7.71	45.2	67.0	2.15	31.2
1974	720.0	20.7	34.7	403.0	8.27	48.7	68.0	2.0	34.0
1975	658.0	19.6	33.6	368.0	7.42	49.6	65.0	1.77	36.7
1976	598.0	20.88	28.6	326.0	7.66	42.5	60.5	2.04	29.6

Source: See footnote 18.

Table 7

The Change Rate of Reserve/Production of Crude Oil
for the World and Selected Countries (1963-76)

	World			Iran			Saudi Arabia		
	R	Q	R/Q	R	Q	R/Q	R	Q	R/Q
1. $(\frac{X_{69} - X_{63}}{X_{63}})/7$	9	8.6	0.2	7.	18.9	-5.	19.	11.4	4.2
2. $(\frac{X_{76} - X_{70}}{X_{70}})/7$	-0.3	3.6	-3.	-1.4	3.	-3.7	-2.	18.	-4.4
3. $(\frac{X_{76} - X_{63}}{X_{63}})/14$	6.	8.5	-1.2	5.	23.9	-4.3	6.	27.	-4.4
4. $(\frac{X_{69}}{X_{63}})100$	162.6	160.	101.	148.6	232.	63.	233.	180.	130.
5. $(\frac{X_{76}}{X_{70}})100$	97.8	125.	78.	90.	121.	74.4	86.	226.	37.
6. $(\frac{X_{76}}{X_{63}})100$	183.4	220.	83.	170.2	434.	39.1	183.	482.	38.

Rows 1-3 = % Annual Change for 1963-1969, 1970-1976 and 1963-1976 respectively.
Rows 4-6 = indices for 1969 (1963 = 100), for 1976 (1970 = 100) and for 1976 (1963 = 100), respectively.

> the oil problem is one of politics and market power, not one of the consequences of depletion of natural resources. To begin, world proved reserves of oil are sufficient to supply rate of consumption beyond the turn of the century. Further, it is well known that production from a given field typically exceeds the proved reserves estimated to be in that field some years earlier. And finally, world proved reserves have grown more rapidly than consumption in the post-World War II period, 7.0% as opposed to 6.6% from 1965 to 1975, for example . . . (15)

If we are interested in R for "a" period, then there is no need for back-dating the proved reserves. However, if we are interested in analyzing the trend of R and its changes over time, then the back-dated reserve is suitable for the analysis.

If the rate of new oil discoveries is less than the rate of extraction for a period of time, it may or may not affect the published reserves. The published reserves remain the same or may even increase over some periods of time but after a while the gap between production and new discoveries will appear and R starts declining. In other words, there are some lags between a reduction of new oil discoveries and its impact on the published reserves. As pointed out above, to eliminate the gap is to back-date the proved reserves to the year of discovery. As an example, the ratio of the published reserves to the rate of production for the world and for some individual countries has been calculated in Tables 5 and 6 and in Figure II-3. This ratio is a decreasing function of time in Figure II-3; in the tables, however, the ratio has remained fairly stable until recent years. This is because the proved reserves are back-dated in Figure II-3 but they are not back-dated in Tables 5 and 6.

Since the early 1960's there have not been any big oil discoveries except in the North Sea and Alaska. But from 1960 the consumption of crude oil has increased more than 200%. As it was pointed out, the effects of the gap between the rate of production and the rate of new discoveries on the published proved reserves may not be seen for a long time. Figure II-3 and Tables 5, 6 and 7 may explain this point. Consider the last 14 years as two periods; period 1 includes the seven years 1963-69 and period 2 includes the seven years from 1970-76. The rate of new oil discoveries for each period has been very low. The combination of Alaskan and North Sea oil is (if we consider the proved reserves) less than the consumption of the world for two years. For the first period, 1963-69, production had a very high rate of growth (60% for the period; 8.6% annually) but the growth rate of published proved reserves was even higher (62.6% for the period; 9% annually). Consequently, the ratio of proved reserves to consumption increased by 1%. However, during the second period production increased only 25% for the whole period (1970-1976), but the growth of reported proved reserves was negative, such that the ratio of R/Q decreased by 21.7%. The news is even worse for some OPEC members; for example, the Middle East's production increased 81.6% during the first period but because the reported proved reserves increased 60%, the R/Q dropped only 3.6%. The production of the Middle East's oil increased only 50.2% during the second period, nevertheless, the ratio of R/Q dropped by more than 37%. There was no new oil discovery during either period (1963-69 and 1970-76) but the impact of the gap between production and new discoveries is by far greater on the reported proved reserves of the second period than on the first period.

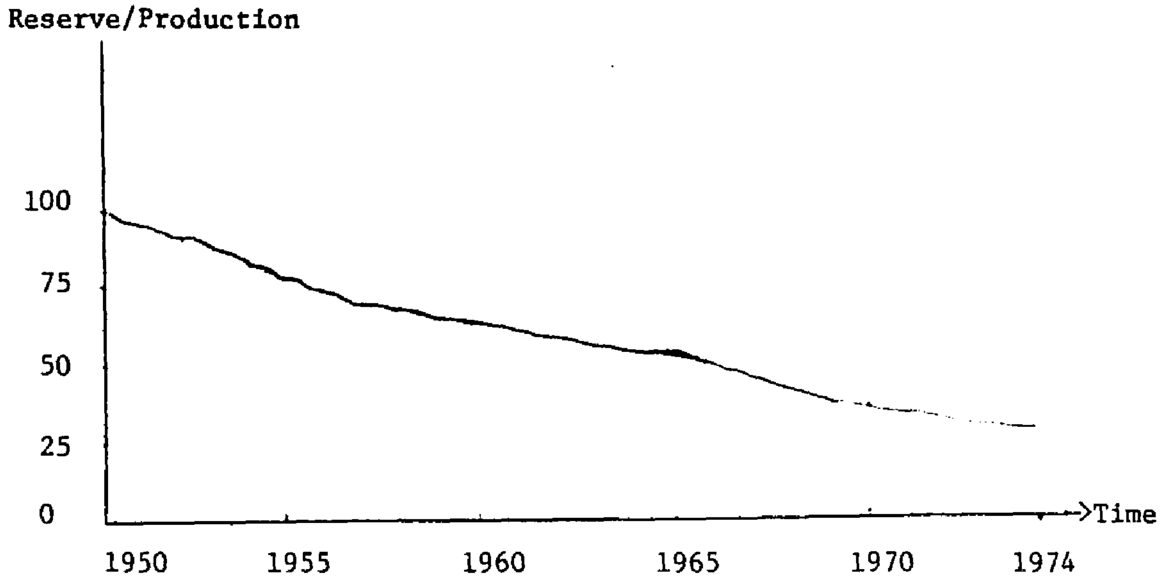

Figure II-3: Ratio of Reserve/Production
for the World

(Reserves backdated to Years of Discovery)

Source: British Petroleum Company Report, 1974.

To summarize our discussion about proved reserves of the world, we should bear in mind that:

(1) The only major oil discoveries during the last 14 years have been the Alaskan and North Sea oil and the combination of both is barely enough for two years' world consumption.

(2) The rate of consumption of crude oil for the world during this period (1963-1976) has increased 120%, from 9.5 b/b in 1963 to 20.88 b/b in 1976.

(3) The known back-dated proved reserves of the world during this period have been a decreasing function of time.

(4) Even if we do not back-date the proved reserves, the ratio of proved reserves to the rate of production has dropped 17.6% during

this period (1963-1976) and 21.7% over the last 7 years (1970-1976).

(5) For the last 7 years (1970-1976) the proved reserves of the United States have decreased 20% from 39 b/b in 1970 to 31.3 b/b in 1976. For the same period the rate of production has dropped 16% from 3.51 billion barrels a year to 2.96 b/b and finally R/Q has dropped 4.5% from 11.1 in 1970 to 10.6 in 1976.

(6) During the last 14 year period the rate of production for the Middle East has increased more than 200% from 2.5 b/b in 1963 to 7.66 b/b in 1976 but the ratio of R/Q has decreased 37% from 76 in 1963 to 42.5 in 1976. For this period the rate of production for Iran increased 334% from 0.53 b/b in 1963 to 2.30 b/b in 1976; during this period the ratio of R/Q dropped 61% from 70 in 1963 to 27.4 in 1976. And finally, the production of Saudi Arabia increased 382% from 0.65 b/b in 1963 to 3.13 b/b in 1976 while R/Q decreased 62% from 92.3 in 1963 to 35.1 in 1976.

B. The Expected Discounted Future Prices (e.d.f.p.)

The statistical inferences of the impact of the e.d.f.p. on user cost and consequently on the market price of crude oil will be presented in Chapter 3, while the remainder of this chapter will provide a background for these analyses through a brief description of the e.d.f.p.'s changes during recent years. The size of e.d.f.p. (and consequently its impact on user cost) is a variable which may be low (negligible) for some years and may be significant for others. It is extremely difficult to explain and describe the changes of e.d.f.p. year by year; nevertheless, it is easy to observe a low and negligible value of e.d.f.p. for the years prior to 1970 and a significant value for 1970 and thereafter.

As it was pointed out in Chapter 1, the fundamental principle of the economics of exhaustible resources is "The net price of the resource, if the market is in competition, (or the marginal profit of each unit of the resource, if competition is imperfect) must increase exponentially over time"; i.e., $p_t = p_0 e^{it}$ or $mp_t = mp_0 (1 + i)^t$. Accordingly, if $p_t = p_0$, for $t = 1, 2, 3 \ldots$, and $i > 0$, we could say the scarcity rent is negligible, i.e., $p_t = p_0 = 0$. Up to 1970 the real price of international crude oil was a decreasing or constant function of time and the nominal price, which was lower than the 1950s level, almost remained the same during the 1960s.

Because the price was the same or was decreasing over time, each producer tried to maximize his profit by maximizing the rate of extraction. Historically, there was almost always excess capacity for each producer and this was the main reason for a decreasing price over time. The relative price of crude oil to labor in the U.S. was 1034 in 1900, 726 in 1920, 213 in 1950, 135 in 1960, and 100 in 1970.[16]

By 1970 the inevitability of an energy shortage was making news in most industrial countries. Although it is not our concern to investigate the reasons for the shortage, but rather the impact of it, it is worth noting that on September 7, 1970, Oil and Gas Journal wrote:

> Oil and gas are two commodities in our inflated economy that are vastly underpriced. Oil men have to get more realistic prices before they can afford to finance greater exploration . . . A few simple figures show what the oil-man is up against. His cost of casing is up 34.4% since 1956; wages are up 52.8%; drilling tools, up 32.4%. Yet crude oil prices rose only 10% from 1956 to 1969. Measured in constant dollars, this represents a decline of 20.2% in comparative value for crude . . . Price is the vital key to solving the energy crisis.

It has been pointed out that the growth of energy consumption is paralleled by the growth of GNP. But, during the late 1960s, the "ratio of energy growth rate to GNP growth rate" increased disproportionately for most countries of the world. The annual rate of energy growth rate for 1925-1950 was only 2.24%, for 1950-1965 it was 4.74% and for 1965-1970 it went up to 5.35%. The growth path for each interval is as follows:

$$q_t = e^{(6.7085 + 0.224t)} \quad \text{for 1925-1950}$$

$$q_t = e^{(5.494 + 0.0474t)} \quad \text{for 1950-1965}$$

$$q_t = e^{(5.096 + 0.05346t)} \quad \text{for 1965-1970}$$

$t = 0$ for 1900

q = million metric tons coal equivalent

In other words, the total consumption of energy grew 20%, 45%, 60% and 66% for the respective periods of 1925-1938-1950, 1950-1960 and 1960-1970. And finally, energy consumption had a rate of growth of 6.68% and 6.0% for 1968 and 1969; during 1970 the energy consumption of the world had a growth rate of 7.32%, the highest growth rate ever.

Now let us look at the sources of energy and their changes over time. The production of coal, historically the major source of energy, has increased over time, too: 30% during the 1925-1950 period and 50% for the 1950-1970 period. Overall, for 1925-1970 the compound rate was 1.6% with a growth path of:

$$q_t = e^{(6.624 + 0.0163t)}$$

$t = 0$ for 1900

q is measured by million metric tons.

However, coal's growth rate was far from enough to match the energy growth rate. The average energy growth rate for the same period of 1925-1970 was 3.75%, with the growth path of:

$$q_t = e^{(6.174 + 0.0375t)}$$

Therefore, coal's share as a source of energy was a decreasing function of time. Its share of the energy market was 83% in 1925; it declined to 61% in 1950, to 47% in 1960 and in 1970 it was only 34%.

By the late 1960s and early 1970s, the price of coal started rising in most industrial countries. In the United States, for example, its price was almost the same during the 1950s and early 1960s, but from 1965 to 1968 it rose 3% annually; during 1968 it went up 8% and it jumped 38% during 1970. It is interesting to note that not only is there a high correlation between the prices of coal and crude oil in the United States, but there is also a high correlation between the price of coal in the United States and the per barrel oil revenue for an OPEC member:

$$p_0 = 38.92 + 0.52\ p_c \qquad r = 0.988 \qquad \text{for 1960-1975}$$

$$r_0 = -190.5 + 2.67\ p_c \qquad r = 0.95 \qquad \text{for 1960-1975}$$

p_0 is the index price of crude oil in the U.S.A. (1967 = 100)

p_c is the index price of coal

r_0 is the per barrel oil revenue (1967 = 100)

Another source of energy is hydro-electricity which has had a very high growth rate. Its production in 1970 was more than 15 times its 1925 production, from 10 million metric tons of coal equivalent in

1925 to 157 in 1970. Its growth rate for this period, from 1925 to 1970, was 6.1% with a growth path of:

$$q_t = e^{(0.7762 + 0.061t)} \qquad t = 0 \text{ for } 1900$$

q is a million metric tons coal equivalent

Its share of the energy market rose from .6 of 1% in 1925 to 2% in 1970; nevertheless, 2% is too low to be considered a main source of energy.

After the Second World War it was expected that by the 1970s or at most the 1980s nuclear energy would become one of the main sources of energy and eventually it would be <u>the</u> major source. But it did not fulfill the high hopes set on it in the last two decades. Development of nuclear energy was behind schedule and by 1970 it became known that its environmental and economic costs were much higher than had been expected. Solar energy, shale oil, tar sands were also considered as potentially being main sources of energy but their commercial use is currently far from a reality.

For the last 30 years, the huge rate of energy growth was made possible by the relatively cheap and abundant supplies of petroleum, natural gas and crude oil. During the ten-year period from 1950-1960, the production of natural gas increased 240%, for 1960-1970 it was 234%. Natural gas accounted for only 3% of energy in 1925; it went up to 10%, 14%, and 20% in 1950, 1960 and 1970,respectively. The compound rate of growth for the entire period, from 1950 to 1970, was 8.63% per year and its time trend was:

$\ln q_t = 1.223 + 0.08628t$

$t = 0$ for 1900

q in million metric tons coal equivalent.

The role of crude oil as a source of energy has been increasing steadily since 1900. The compound rate of growth since the turn of the century has been 6.93% per year for the world. Its growth path is:

$q_t = e^{(4.787 + 0.0693t)}$

$t = 0$ for 1900

q in million barrels per year.

This rate of growth means the production will double within each ten-year period, i.e.,

$$q_{1970} = 2q_{60} = 4q_{50} = 8q_{40} = 16q_{30} = 32q_{20} = \ldots = 128q_{1900}$$

The actual production in 1970 was more than double that of 1960, more than quadruple that of 1950, 8 times that of 1940 and almost 128 times the production of 1900. As we see in Table 8, the actual production was 6 billion barrels in 1956 and 12 billion barrels in 1966; and it was 5.00 billion barrels, 10.77 and 20.70 billion barrels for the years 1954, 1964 and 1974, respectively.

This rate of growth was, more or less, the same until 1968. The rate of growth for 1968 and 1969 was higher than usual, 9.4% and 8.5%. The rate of growth during 1970 was as high as 10%. As it was pointed out, these high rates of growth of production greatly diminished the excess capacity and consequently put pressure on the price level. The price of crude oil, similar to that of coal, started moving up in

Table 8

The Trend of The World Crude Oil Production Since 1900

Year	Actual: Q_t	Estimated: $\ln \hat{Q}_t = (-2.12 + 0.0693t)$ (t = 0 for 1900)	$\frac{Q_t - \hat{Q}_t}{Q_t}$
1900	0.12	0.12	0
1940	2.0	1.92	+ 4 %
1950	3.84	3.84	0
1951	4.2	4.11	+ 2 %
1952	4.5	4.41	+ 2 %
1953	4.7	4.72	0
1954	5.0	5.06	0
1955	5.6	5.43	+ 3 %
1956	6.0	5.82	+ 3 %
1957	6.5	6.23	+ 4 %
1958	6.9	6.68	+ 3 %
1959	7.2	7.16	0
1960	7.63	7.67	0
1961	8.2	8.22	0
1962	8.9	8.82	0
1963	9.54	9.45	0
1964	10.77	10.13	+ 6 %
1965	11.0	10.86	+ 1 %
1966	12.0	11.62	+ 3 %
1967	12.8	12.45	+ 3 %
1968	14.0	13.34	+ 5 %
1969	15.2	14.32	+ 6 %
1970	16.7	15.35	+ 9 %
1971	17.6	16.45	+ 7 %
1972	18.5	17.63	+ 5 %
1973	20.3	18.90	+ 7 %
1974	20.7	20.25	+ 2 %

Table 8 (Continued)

Year	Actual Q_t	$\ln \hat{Q}_t =$ Estimated $(-2.12 + 0.0693t)$ (t = 0 for 1900)	$\frac{Q_t - \hat{Q}_t}{Q_t}$
1975	19.6	21.70	- 10 %
1976	20.88	23.26	- 10 %
1977		24.93	
1980		30.69	

Source: (1) United Nations Statistical Yearbooks.

(2) Oil and Gas Journal, Worldwide Issues.

Note: The production in this table has been reported by billion barrels; estimation and calculations have been done by the author.

international markets:[17]

> In Western Europe, the rise in petroleum product prices was clearly in evidence during 1970. By September, the price of fuel oil, especially oil of the heavy qualities, had risen quite considerably. Thus, in Rotterdam the price had increased during one year from $10 to $25 per ton. In the coastal regions of Italy, the price increased from $8.50-$9.00 to $23-$25 per ton. In Sweden, the price rose to $30 per ton.

The combinations of the following events had a double effect on the behavior of each oil-producing country (and/or company):

D_1 - An increase of the rate of growth of energy consumption and the expectation that the rate of growth will remain high in the foreseeable future.

D_2 - The continuous decline of coal's share of energy production, and the continuous increase in its price--especially during 1970 when it jumped more than 30% in the United States, for example.

D_3 - The delay in developing nuclear energy, solar energy, oil shale and tar sands, since it is almost a certainty that their cost will be too high, given the existing technology, to compete with coal or petroleum as energy sources for at least 20 years.

D_4 - The increasing role of petroleum in producing energy (from 38% of the market in 1950 to 64% in 1970), and the expectation that this trend will continue for a while and remain the same at least to 1990.

D_5 - A high rate of growth of production for OPEC members, the increasing role of their oil in international markets and the expectation that this trend will continue or remain the same at least until 1990.

i_1 - The psychological impact of the energy crisis and the news that energy shortages would be with the world for a long time.

i_2 - The increasing revenues for OPEC members because of the high rate of growth of production.

i_3 - An increase in the internal political stability of most OPEC members.

i_4 - The continuous world-wide inflation, instability of the world monetary systems and the devaluation of the British pound.

Q_1 - A continuous decline in the backdated proven reserves, despite a high rate of growth for extraction.

Q_2 - Lack of success in finding cheap oil reserves. The only oil discoveries made during the whole decade of the 1960s were in the North Sea and Alaska where the reserves are relatively small and their cost is very high.

The first effect of these events on the oil-producing countries was the reconsideration of their policy toward maximization of production to maximize income. Maximizing production was not desirable any more, i.e., user cost became a significant element in each decision-making process. This effect itself was the cause of a second effect: a reduction of the cost of cooperation. If maximizing the rate of extraction is not the objective of the oil producing countries, then why not act collectively? The cost of cooperation is negligible even if the collective action requires a reduction of production or a reduction of the rate of production growth.

These events and their economic effects made the following events inevitable: the price of crude oil increased because of a shift in its user cost function, even though its operational cost remained the same. It was dictated by the law of supply and demand which everybody in the industry, and some outside as well, knew and expected. Sometimes some economists are the last people to see the invisible hand. This occasion was one of them. As Financial Time, November 17, 1970 wrote:

> In retrospect, 1970 may be looked back on as a year in which the balance of power between oil companies and the producing states shifted. The improvement in the latter's terms has been possible largely as a result of the tightness of the supply situation.

As was expected, OPEC's twenty-first conference, held in Caracas from December 1 to 9, 1970, opened a new chapter in oil industry history. For the first time, OPEC acted collectively to increase the posted price and the share of revenues for producer members from 50% to 55%. The per barrel revenue of the producing countries, which was almost the same during the previous ten years and lower than that of the 1950s, increased approximately 6.5% in 1970, 40% to 50% during 1971 and the price increase was assured for the coming years.

The preceding events proved one point: the era of constant or decreasing price had past; oil had become a scarce commodity and was subject to the laws of the economics of exhaustible resources.

Except for Professor Adelman and others who believed oil was an abundant commodity and therefore the gap between the price and the cost must narrow by lowering the price, it was almost universally accepted among the industry that the price of oil was increasing over time. For example, Professor Issawi wrote in 1972:

> First there is the question of Middle Eastern and Northern African oil prices. All indications are that these will rise, steadily and appreciably, over the next decade or two. In itself, such a development is not catastrophic, since the main importers (Western Europe, Japan and, increasingly, the United States) are rich and since the prices of their exports to the oil producing countries are also rising steadily. Moreover, an increase in oil prices may serve a very useful economic function by forcing an overdue reduction in consumption, stimulating exploration for oil in other regions, and encouraging the development of alternative sources of energy. Compared to costs of production, the price of Middle Eastern and North African crude oil has been very high. But compared to the price consumers are presently paying for oil products, including the taxes levied by their own governments, it has been low. And, taking a broad social point of view, for a commodity which may be exhuasted within a few decades, oil is at present being provided far too cheaply. (10)

During 1971 and 1972, the demand for energy continued on its usual growth path and petroleum was the major source of satisfying this demand. During these years the energy crisis took on new dimensions. Because of the reduction of oil deposits, the United States--the largest producer country in the world--and Venezuela--until 1970, the largest oil exporting country--reduced their production. The result of some intensive research indicates that there will be no cheap oil left to be discovered and that the African and Middle Eastern oil remains the cheapest in the world.[16]

Because of the reduced production rates of the United States and Venezuela, the pressure on Middle Eastern oil increased. The compound growth rate of production for Middle Eastern oil during the period from 1950 to 1970 was very high, i.e., 11%. The growth path was:

$$q_t = e^{(-0.5411 + 0.11t)}$$

$t = 0$ for 1900

q = billion barrels per year.

During 1970 this rate was 12.3%, in 1971 it was 11.7% and in 1972, 10.6%.

1973 became another historical year for the oil industry. In early 1973 for the first time in oil history, a producer country, Kuwait, restricted the rate of production, i.e., conservation measures were applied. Almost simultaneously, Canada restricted exports of petroleum to the United States and she, too, utilized conservation methods.[17] The United States and Venezuela continued to reduce their production. These restrictions of supplies coincided with another demand peak for energy in general and petroleum specifically. As in 1970, or perhaps even worse than that, the energy crisis became front page news.

Per barrel oil revenue, which had reversed its direction in 1970 and increased by approximately 6.5% in 1970, jumped to 45% in 1971 and continued to increase as was expected during the later years. It increased another 9% in 1962, 4.7% by January 1, 1973, and 6% by April 1, 1973.

During 1973, demand for oil increased more than was expected and so did the price of oil. By October 1, 1973, the price was hiked another 10% and by November 1 it increased 80%. Despite a reduction of oil production during the last quarter of the year (because of a partial embargo) the production of energy, oil and Middle East oil reached record highs of 6.1%, 10% and 16.6% respectively for this year.

By this time (1973) the operational costs of international crude oil productions were almost unchanged but the user costs moved upward. The forces which pushed user costs (U.C.) upward can be divided into to categories, individual and collective. The individual forces were mainly those which were mentioned on pages 87-88 for 1970, however, this time with a higher degree of certainty and intensification of most of the forces. For each producer, the shift of U.C. became evident and feasible; for instance, The United States, Canada, Kuwait and Venezuela reduced their productions. Other producers were not eager to produce more and sometimes reluctant for any increase of production in expectation of the price increase in the future. As it has been pointed out, all these were coinciding with a strong demand and the expectation that the trend would continue for a long time.

The voluntary reduction and/or desire for limited growth of production by the producing countries--members or non-members--gave OPEC a new and unprecedented strength. OPEC became a viable organization and every evidence indicated that it would remain strong in the foreseeable future.

The strength of OPEC and the expected demand were considered seriously by the creators of the "As-If" agreement of 1928. In short, the ensuing events not only increased the individual user cost but they reduced the cost of cooperation and increased its benefits. OPEC members on one side and the international oil companies on the other side could easily cooperate, or collude, among each other and between the two groups.[6]

FOOTNOTES

[1]Incidentally, a modern chemist also condemns the oil production because he believes that oil is needed to feed the human being, not to waste and burn it.

[2]As it was pointed out in the Introduction, there are some valuable studies in the field such as: M. A. Adelman, The World Petroleum Market; P. Bradley, The Economics of Crude Oil Production; H. Frank, Crude Oil Prices in the Middle East; and T. Rifai, The Pricing of Crude Oil. However, these studies do not consider oil subject to the economics of exhaustible resources. Consequently, they could not explain or predict the price changes of the recent years.

[3]F. M. Fisher, Identification Problem in Economics (New York: McGraw Hill, 1966).

[4]S. Clark, The Oil Century (Norman: University of Oklahoma Press, 1958).

[5]The term "stable" has been used for the trend of the price; in other words, A in figure II-4 is stable but B is not.

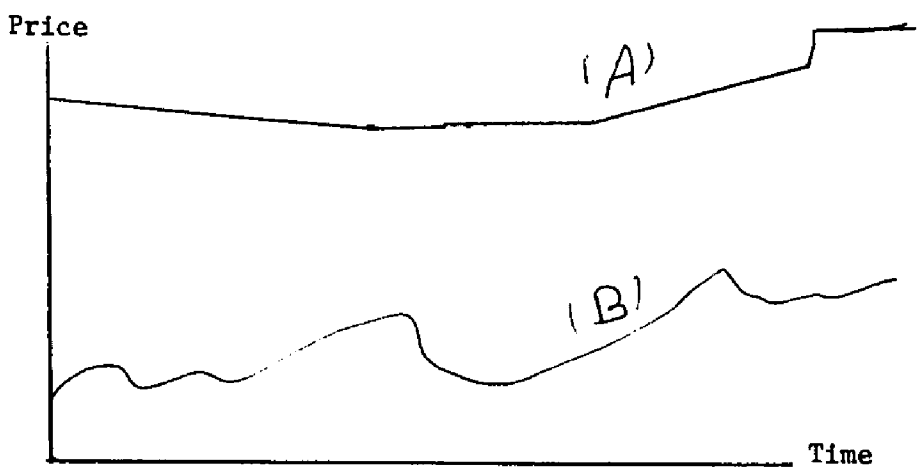

Figure II-4

The price stability over time

[6]J. M. Blair, The Control of Oil (New York: Pantheon Books, 1976).

[7]For detail, see G. Stocking, Middle East Oil.

[8]See Multinational Oil and footnote 7.

[9]See J. Ridgeway, The Last Play, p. 171 and O'Connor, World Crisis in Oil, pp. 277-299.

[10]C. Issawi, Oil, The Middle East and the World (New York: Library Press, 1972).

[11]J. Griffin and P. Gregory, "An Intercountry Translog Model of Energy Substitution Responses," AER (December 1976):845-57.

[12]J. Darmstadter, Energy in the World Economy, p. 12.

[13]Oil and Gas Journal (November 11, 1974).

[14]For more detail see M.A. Adelman, The World Petroleum Market.

[15]See J. Myers, "Oil Imports, Energy Conservation, and Economic Growth," p. 3.

[16]W. Nordhous, "Resources as a constraint on growth," AER (May 1974):22-26.

[17]F. Rouhani, The History of OPEC (New York: Praeger, 1971).

[18]The statistics have been compiled and calculated by the author from the following sources: American Petroleum Institute, Annual Statistical Review (Washington D.C.: Annual); American Petroleum Institute, Petroleum Facts and Figures (Washington D.C.: Biennual); The Oil and Gas Journal, Worldwide Issue (Tulsa: Annual); United Nations, Statistical Yearbook (New York: Annual); United States, Department of the Interior, International Petroleum (Washington D.C.: Annual); U.S. Mines Bureau, Mineral Yearbook (Annual); Statistical Office of the United Nations, World Energy Supplies 1950-1974 (statistical papers, series J No. 19).

CHAPTER 3

THE INTERDEPENDENCE OF SUPPLY-DEMAND AND THE PRICES OF PETROLEUM: AN EMPIRICAL INVESTIGATION

I. METHOD

Numerous economic, political (institutional), technological, and psychological factors have determined, and still influence, the market price of international crude oil. Some of these elements may not be independent from other factors and in some cases they are certainly interdependent. The variety of the factors, their interdependence, and the difficulty of measurement, make a complete and comprehensive empirical study of the international crude oil market intractable. Nevertheless, by choosing the most important elements of supply and demand, by substituting proxy variables for the non-measurable factors, and by using the partial equilibrium analysis method, an empirical study aiming to explore the mechanism of the price of international crude oil is practicable.

The major purpose of this chapter is to develop an econometric model for the international crude oil market which will explain and measure the market price of this resource. To achieve this objective, the forces affecting the market price must be identified and quantified; in addition, the influences that each factor--or set of factors--has on the price must be measured. Identification, quantification, and measurement require certain assumptions and simplifications regarding the nature and extent of the variables.

Two sets of explanatory variables cause variation of the market prices; namely, the set of supply and the set of demand variables. A relationship which considers offer price (or quantity) as the dependent variable, and the rest of the supply set as the explanatory variable, is called QUASI SUPPLY FUNCTION.[1] A similar definition has been used for the QUASI DEMAND FUNCTION.[2] If we estimate the quasi supply and quasi demand equations, we can estimate (or predict) the market price and/or the rate of extraction. Another method of estimating the market price is through the REDUCED FORM equation. Before reporting the regression results of these functions (i.e., structural and reduced-form equations), a review of the empirical literature followed by the definition and clarification of the terms or symbols used in this report will be helpful.

A. A Brief Review of the Empirical Literature

Paul Bradley's book, The Economics of Crude Petroleum Production (1966), can be considered a pioneer in empirical work on the cost and supply of crude oil. He established a tenable analytic framework in order to construct the cost-output curve for a particular region at a given time. Originally a Ph.D. dissertation, his book is highly technical and it is extremely difficult to summarize; nevertheless, the following notes may be helpful as a review of his approach to measuring the cost of crude oil.

After presenting some preliminary economic, geologic, and mathematical background material, he defines development cost, which he considers *the* cost, as:

$$z = (E/Q)\ (D + i)$$

where: z = development cost \$ per barrel

$\frac{E}{Q}$ = capital output ratio \$ per barrel

D = decline rate of the well

i = discount rate.

His empirical investigations are mainly an estimation for "average production rate per well in a period" (Table 9) and "annual capital expenditure" (Table 10) for some different regions and some different periods. As a sample, he calculates development cost for Abqaiq in 1954, given i = 15%, 15.3 cents per barrel.

Table 9

Production Rate of Crude Oil: Bradley's Approach

(Regression Variables)

$\bar{q} = a - dQ + gsU + htU$

Symbol	Description
$\bar{q}$	average production rate per well in period t
Q	cumulative out-put
U	index of field utilization
s,t	dummy variables
F	index of use of artifical lift

Source: P. Bradley, The Economics of Crude Petroleum Production, (Amsterdam: North Holland Publishing Company, 1967), p. 53.

Table 10

Capital Expenditure: Bradley's Approach

$$E = a + [b + ct]\ [\psi(W + \frac{1}{3}C)] + dS'$$

Symbol	Definition
E	annual capital expenditure for production facitlites, millions of dollars
a	constant (residual expenditure), millions of dollars
b	average cost per well of standardized depth, millions of dollars
c	annual change in cost per well of standardized depth
t	time, years
ψ	depth factor
W	total number of wells drilled
C	number of wells completed as producers
d	average cost per unit of surface capacity, thousand dollars per daily barrel
S'	increments to surface capacity (two-year moving average), barrels per day

Source: P. Bradley, The Economics of Crude Petroleum Production, (Amsterdam: North Holland Publishing Company, 1967), p. 72.

Professor Adelman of M.I.T., one of the leading academic experts on the oil industry, has long examined the prices and costs of crude oil. The results of his empirical investigations have been reported in The World Petroleum Market (1972). He organized his cost study according to the conventional three-way division into operating, development, and finding cost. However, he combined three types of costs into one: "development cost has swallowed operating cost on the one side and finding cost on the other."[5] He calculated the long-run supply price (1970-1985) for different countries (table 11) and his conclusion is:

> For at least 15 years we can count on, and must learn to live with, an abundance of oil that can be brought forth from fields now operated in the Persian Gulf at something between 10 and 20 cents per barrel at 1968 prices and in some other provinces at costs even lower when account is taken of transport.
>
> Price is many times cost, and no matter who gets what percent of profit, it will pay (as it does now) not to buy from the abundant available supply, but instead to spend large amounts on exploration and development in the reasonable hope of recouping the investment and making a profit after even a few years of operation at current or even much lower prices. If oil exploration continues at a brisk pace, new fields will come in and available reserves will exceed the minimum figure used here. The supply price will rise less than is calculated here; it may well decrease in the future as it has in the past. (6)

Table 11

Long-run Supply Price of Crude Oil:
Adelman's Estimation and Prediction

Country	Long-run Supply Price (1970-85) $
Iran	0.20
Iraq	0.20
Kuwait	0.20
Saudi Arabia	0.20
Venezuela	0.64

Source: M. A. Adelman, The World Petroleum Market, (Baltimore: The Johns Hopkins University Press, 1972), p. 76.

The basic difference between the Adelman-Bradley approach to the problem of constructing the cost-output curve and my approach is that they ignore user cost because, de facto, they assume a negligible value for the scarcity rent, while I consider the user cost as the cost. Refering to "exhaustible resources" and the concept of user cost, Adelman says,

> But this is not an interesting or important problem, nor is user cost a helpful concept because it assumes the unknown we should be solving: the future price, which itself depends on future incremental cost. In any case, the size of the problem itself shrinks with declining output. Let us return to a more important aspect: investment decision.(7)

I have shown in Chapter 2 how related events have affected scarcity rent and consequently the size of the user cost of international crude oil; I have also shown in Chapter 1 that as far as scarcity rent is significant, the user cost function constructs the cost-output curve for a resource. Accordingly, we expect the user cost model to explain the price variations by the variations of the elements of demand and/or user cost (supply) functions.

B. Definition of the Terms and Symbols

Crude oil is an exhaustible resource subject to the principles of economics of the mine; moreover, the crude oil market is not of perfect competition. Therefore, the supply of this resource can be best described by the theory presented in Chapter 1. However, to estimate the cost-output curve for each producer country, or for the set consisting of nearly all oil-producing countries (OPEC), certain assumptions must be made. We may thus consider a producer country (or a group of producers such as OPEC) as a mine owner and construct the quasi supply function, cost-output curve. The quasi supply function for a producer country or OPEC can be defined as:

$$(1) \qquad P_{st} = f(Q_t, R_t, F_t; OPR_t)$$

where: "P_{st}" is the user cost function, i.e., it represents the minimum price at which a given quantity, during the period t, will be forthcoming.

"Q_t" is the rate of extraction, production, during year t.

"R_t" is the total proved reserves at the beginning of the year t.

"F_t" is a PROXY VARIABLE representing the impact of expected discounted future prices on the present price. This proxy variable can be defined by A or B:

(A) If time is considered to be discrete:

$$F_t \equiv \left(\sqrt[5]{\frac{P_t}{P_{t-5}}}\right) - 1;$$

(B) If time is considered to be continuous:

$$F_t \equiv \frac{\ln \frac{P_t}{P_{t-5}}}{5}$$

Either A or B mean: "The trend of the market price is an indicator for the expected discounted future prices." The rationale of substituting "F_t" for "expected discounted future prices" is the substitution of a cause for its effect. After all, a mine owner (like the owner of any capital asset) asks his asset: "What have you done for me lately?"

"OPR_t" is the OPEC-share of the world's energy production, i.e.

$$OPR_t = \frac{\text{Total Oil Production of OPEC During Year t}}{\text{Total Energy Production of the World During Year t}}$$

In other words,

$OPR_t \equiv$ (OPEC-share in producing crude oil) (Oil-share in producing energy)

If the competition were perfect there would be no need to include this variable in the relation because its coefficient would be insignificant, anyway. However, whenever the market competition is imperfect, the coefficient of this variable may be significant. The necessity of including OPR_t is shown by the following examples:

Example 1: In order to identify the supply function when the market for a commodity is pure competition, we have to assume that the supply of the commodity is stable over time but that the demand function is fluctuating. It is the shift of the demand function that helps us to trace or to identify the supply curve of the commodity.

Consider a monopoly such as in figure III-1, where the cost-output curve (marginal cost) is stable but demand is fluctuating and the observed points are $A(q_1, p_1)$, $B(q_2, p_2)$, $E(q_3, p_3)$, etc. It is obvious that we cannot trace the cost-output curve from the observed points alone. Nevertheless, it is possible to find an auxiliary variable which has the properties of (1) transforming the observed points to new levels such as $\acute{A}(q_1, p_1)$, $\acute{B}(q_2, p_2)$, $\acute{E}(q_3, p_3)$, etc. and (2) the regression curve of these transformed points will be parallel to MC. Accordingly, in order to measure the slope of the marginal cost, it is enough to identify and trace the transformed curve and measure its slope. Actually, if we check for the correct intercept, the transformed

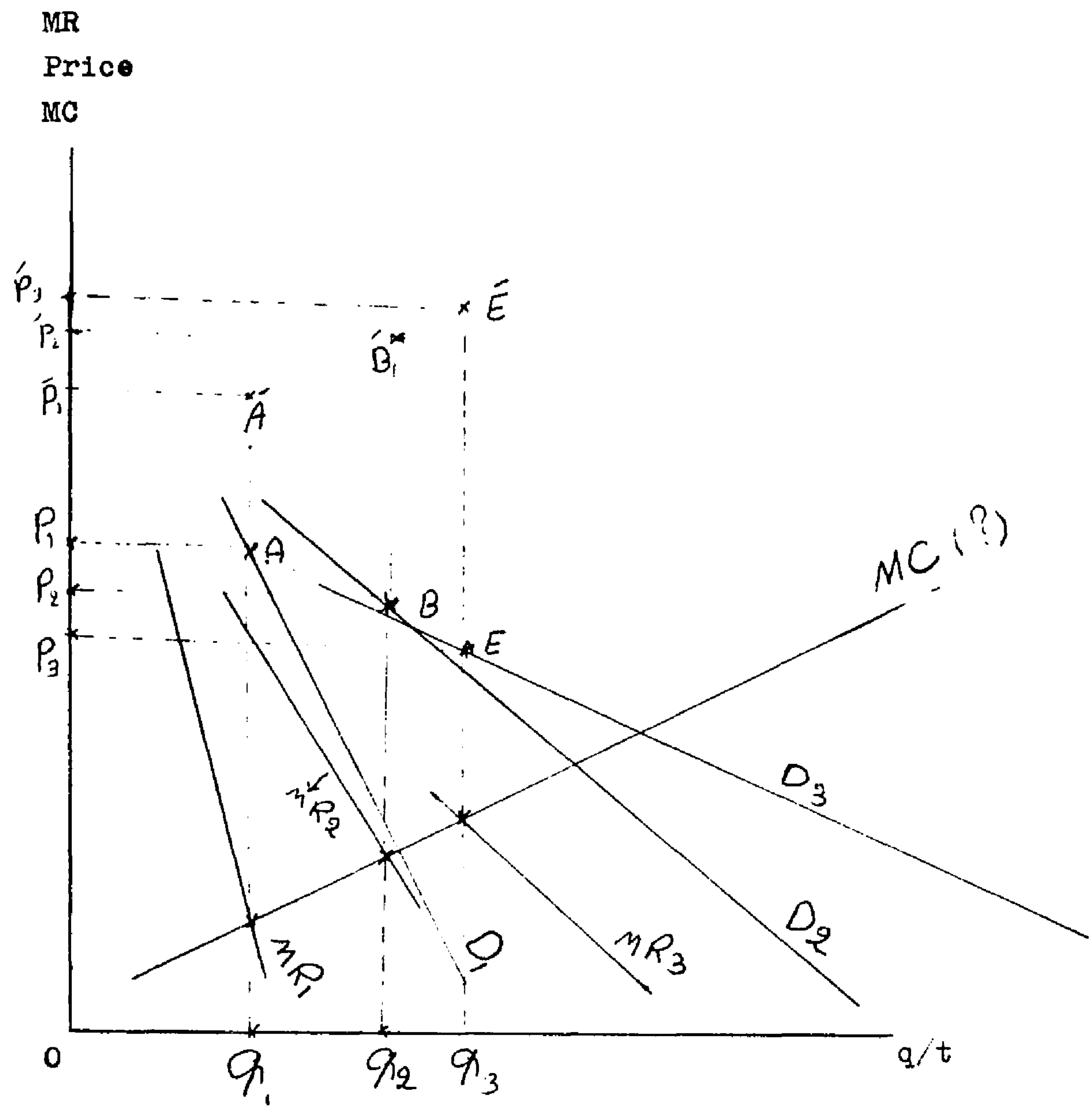

Figure III-1.

Tracing MC: the case of monopoly

curve can be used instead of MC. For the problem under investigation, OPR_t can be used as the auxiliary variable which has the above properties.

Example 2: Assume a hypothetical cartel. The members of which have no chance to increase their production beyond their quota, and assume their marginal cost functions remain the same, but an increase in quota coincide with a reduction of the price (see figure III-2). In this case, too, the cost-output function of a member (MC in figure III-2) can be estimated by observed prices and quantities--such as A,

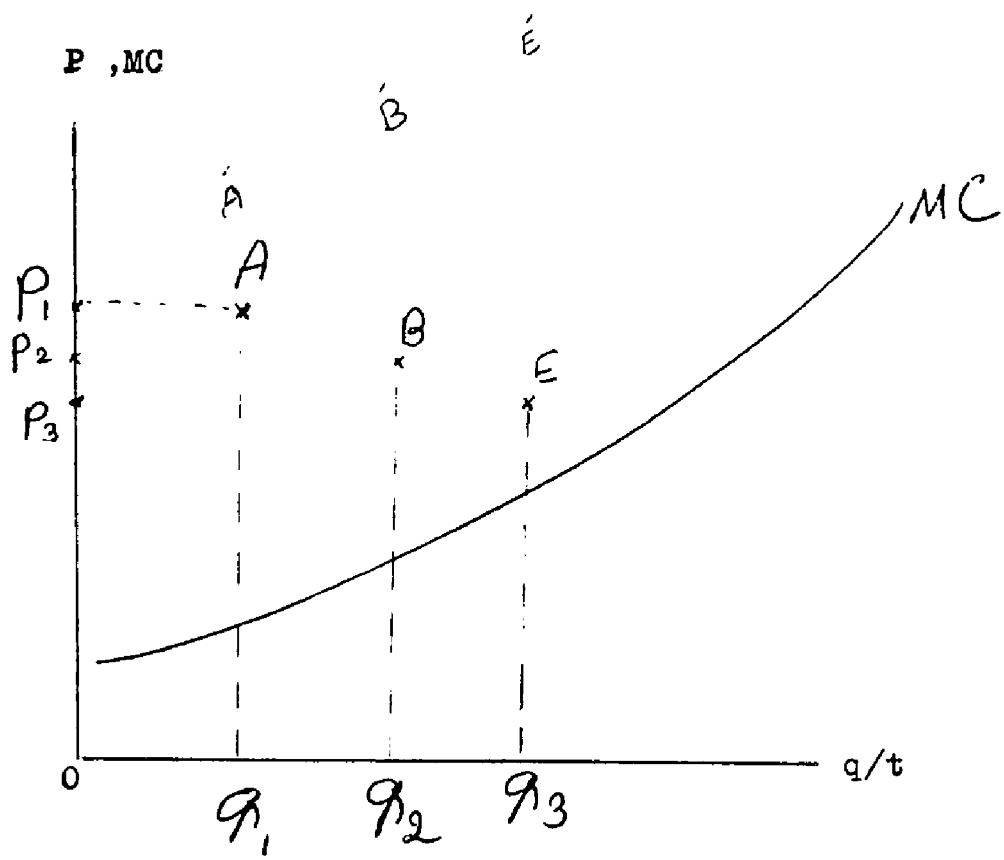

Figure III-2.

Cartel's price and MC of a member's firm

B, E, etc.--if and only if we include other explanatory variable(s) which is (are) necessary for the estimation.

Although we have said that demand gets a minimum of our attention, without it this study would be incomplete. Demand for crude oil, from the oil-producer's point of view, is related to the production of energy and the price of other sources of energy such as coal. In other words, the quasi demand function for crude oil is:

$$(2) \qquad Q_{dt} = f(P_t, E_t, PL_t)$$

where: Q_d is demand for crude oil in period t.

P_t is the price of crude oil.

E_t is production of energy

PL_t is the price of coal which is the chief substitute for oil.

Having presented the set of supply and demand variables, we will now specify their units of measurement.

"$\underline{Q_d}$" or "$\underline{Q_s}$": The quantity of crude oil is measured by billion barrels per year. We assume that its quality, for each producer, has been the same over time.

"$\underline{P_t}$": Numerous prices are used in the international oil markets including "Posted Price," "Realized Price," etc. To standardize the unit of measurement the term PRICE or MARKET PRICE, P_t, in this chapter refers to "the annual average per barrel revenue received by OPEC, or a producer country, measured by U.S. Dollars (current or constant)."

There is a considerable gap between the amount which a consumer pays for a barrel of crude oil, and the amount which a producer country receives for the same barrel of crude oil. This gap includes extraction cost, transportation cost and the international oil companies' profit.

Nevertheless, this study emphasizes the estimation of quasi supply function; therefore all the prices of crude oil in this study (supply, demand, and equilibrium price) have been based on producer's receipts not consumers' cost.

"R": The reserve of crude oil of each country, or of OPEC as a group, is an estimation of "back-dated proved reserves" measured by billion barrels of crude oil.

"E": This variable is the total energy production of the world during a year measured by million metric tons coal equivalent.

"PL": The market, wholesale, price of coal in the U.S.A. (current or constant dollars).

"OPR": Definition of OPEC-share was given on page . OPEC was founded by five countries, IRAN, IRAQ, KUWAIT, SAUDI ARABIA, and VENEZUELA, in 1960 but the number of member countries increased from 5 in 1960 to 13 in 1973. However, the period of this study starts from 1957; consequently, the data refering to OPEC refers to data of all 13 producer countries (as a group) for the period of this study, 1957-1976 or 1956-1973.

II. RESULT[8]

The regression results of OLS and TSLS for dependent variables P, P_s, Q_s, and Q_d (of OPEC and some member countries) have been reported by tables I-10 in Appendix III-A. The results are self-explanatory and consistant with the hypothesis of this paper. Nevertheless, it may be useful to clarify some of these relations and briefly present an economic explanation for those results.

A. P_{st} or the User Cost Function

The "Average user cost" or "supply price" of OPEC for the period 1957-76 is the dependent variable in equation 3:

(1) $$P_{st} = f(Q_t, R_t, F_t, OPR_t)$$

(3) $$\ln P_{st} = \underset{(6.7)}{35.1} + \underset{(1.6)}{0.43 \ln Q_t} - \underset{(-5.6)}{4.8 \ln R_t} + \underset{(20)}{4.4\ F_t} - \underset{(2.2)}{0.61 \ln OPR_t}$$

The price is in current dollars;

$F(4, 15) = 1811.11$

standard error as percentage of mean = 0.9

$R^2 = 0.99$; D.W. = 2.03

The multiple correlation and the associated F-statistics, with t-ratios for the relationship between the dependent and explanatory variables show that the dependence between P_{st} and the explanatory variables are substantial.

If price is considered constant, i.e., $\frac{\$}{PI}$, the regression result would be:

(4) $$\ln P_{st} = \underset{(2.1)}{14.2} + \underset{(1.6)}{0.55 \ln Q_t} - \underset{(-1.25)}{1.38 \ln R_t} + \underset{(8.6)}{2.4\ F_t} - \underset{(-2.1)}{0.75 \ln OPR_t}$$

D.W. = 1.99

$R^2 = 0.98$

The dependent variable in equation 3 and 4 is the "Average User Cost" measured by the current or constant dollars. This variable may be called the "quasi supply price." Accordingly, equation 3 and 4 represent "the cost-output curve" or "the quasi supply function." Although we are not concerned with the precise influence of each particular explanatory variable on P_s, nevertheless, relations 3 and 4 yield adequate information on the direction and extent of the influence of each explanatory variable on P_s. These influences may be examined briefly:

"$\underline{Q_t}$": The influence of Q_t on P_{st} is not significant. Viewed statistically, the low t-ratio for this coefficient is the result of high correlation between this variable and OPR_t. Viewed theoretically, the model presented in Chapter 1 indicates the rate of production may or may not affect the user cost. If, for example, the price elasticity of future demands (which is long-run) is very high, the user cost function would have a high elasticity. Consequently, the influence of the current rate of production on the current user cost would be insignificant.

"$\underline{R_t}$": According to relation 3, the probability that a change of R_t causes a change of the current user cost in the opposite direction (ceteris paribus) is more than 0.999. This is similar to that seen in Chapter 1: $\frac{\partial UC_t}{\partial R_t} < 0$. Equation 3 simply quantifying this inequality and measuring the reserve elasticity, i.e., a decrease of 1% of proved reserve will cause an increase of the user cost, P_{st}, by 4.8%. When we use the constant dollar, equation 4, the R's coefficient is also negative ($\frac{\partial P_{st}}{\partial R_t} < 0$); however, it is less significant than the current dollar, equation 3.

It is possible that equation 3 over-estimates R's significance and equation 4 underestimates it. Relation 3 over-estimates the influence of R_t on P_{st} since for the last 20 years R_t has been relatively stable or decreasing. During the same period the price index for international commodities has been stable or increasing. Consequently, equation 3 which does not exclude this common effect seems more significant than it actually is. Relation 4, on the other hand, has certain difficulties. The United Nations' General Commodity Price Index which has been used as the price index may or may not be an accurate price index for a producer country or for OPEC. In any case, as far as the existance and the direction of the influence can be determined, the exact size of the influence is not important to our model.

"$\underline{F_t}$": That the influence of F_t on P_{st} (in equations 3 and 4) is the most emphatic and strongest in comparision with other explanatory variables, is not surprising. These relations simply resemble the real world; if there is no future need for crude oil, its user cost is hardly more than the price of sands in the desert.

The partial correlation coefficient between F_t and P_{st} is 0.98 for equation 3 and 0.91 for equation 4. On the other hand, the probability of $\frac{\partial P_{st}}{\partial F_t} > 0$ is more than 0.99999 for both equations. An increase of 1% of F_t will increase P_{st} by 4.4% using the current dollar, while it will increase P_{st} only 2.4% using the constant dollar. Considering the rate of inflation of the last 20 years, both of these figures can be acceptable.

"OPR_t": The coefficient of this variable (for both equations 3 and 4) is negative; therefore, the demand function for the resource is generally elastic, i.e., to increase its share of market, OPEC must offer a lower price. However, this negative coefficient does not mean that the correlation between OPR and the market price is low and/or negative. On the contrary, this correlation is high and it is positive. To be precise, it is 0.66 (for current dollars). Why is it the case that the partial correlation between P_{st} and OPR_t is negative but the correlation between these two variables is positive? The answer may be seen in figure III-3.

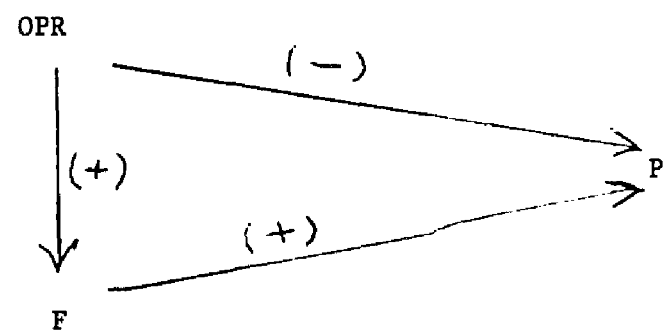

Figure III-3

Direct and Indirect Effect of OPEC-share on User Cost

OPR influences P_s both directly and indirectly. In the former an increase of OPR_t must coincide with a price cut (ceteris paribus). In the latter, an increase of OPR_t will increase the expected future price, F_t:

If OPR↑ → uncertainty↓ → discount rate of the future↓ → expected future price↑ → F↑

which in turn will cause an increase of P_{st}. Finally, partial correlation between OPR_t and P_{st} is -0.50; correlation between F_t and OPR_t is +0.69; and partial correlation between P_{st} and F_t is +0.98 (all measured in the current dollar).

Note 1: We have seen that the user cost model works well for the period of 1957-76. Does it also function properly for the period prior to the price increase of 1973-74? For the function of the model in this case, see equation 5 which presents the regression results for 1957-73.

$$\ln P_{st} = \underset{(7.8)}{21.8} + \underset{(2.8)}{0.17} \ln Q_t - \underset{(-6.1)}{2.7} \ln R_t + \underset{(23.)}{4.6} F_t - \underset{(-4.3)}{0.28} \ln OPR_t \quad (5)$$

(Prices are in the current $)

D.W. = 3.29; R^2 = 0.99

Standard error as percentage of mean = 0.22

Generally, these results are quite similar to those in equation 3, except that the coefficient of R is higher in equation 3. This indicates that the producers paid more attention to the proved reserves in later years than they had before.

Note 2: The OLS and TSLS regression results for the five original members of OPEC (Iran, Iraq, Kuwait, Saudi Arabia and Venezuela) have been reported by tables 2-6 in Appendix III-A. The statistical inferences and the economic explanations of those regression results for Iran, Iraq, Kuwait, Saudi Arabia and Venezuela are, as it is expected, similar to those of OPEC, i.e., for each of those member countries, $\frac{\partial P_{st}}{\partial R_t} < 0$ and $\frac{\partial P_{st}}{\partial F_t} > 0$; moreover, dependency between the user cost, P_{st}, and the set of explanatory variables is substantial.

B. P_t or the Market Price

The market price of crude oil, or of any other commodity, is a dependent variable and its value is determined by interaction of many variables. There are two methods to estimate the market price: the estimation of structural equations (supply and demand) and the estimation of reduced-form equations. This section presents the regression results of the reduced-form equations. The estimation of the structural equations will be presented in Section III.

If, from the producer country's point of view, the demand and supply schedule of international crude oil can be summarized as (6) and (7):

(6) $$Q_{st} = f(P_t, R_t, F_t, OPR_t)$$

where: $$\frac{\partial Q_{st}}{\partial P_t} > 0; \quad \frac{\partial Q_{st}}{\partial R_t} > 0; \quad \frac{\partial Q_{st}}{\partial F_t} < 0; \quad \frac{\partial Q_{st}}{\partial OPR_t} > 0$$

(7) $$Q_{dt} = f(P_t, E_t)$$

where: $$\frac{\partial Q_{dt}}{\partial P_t} < 0; \quad \frac{\partial Q_{dt}}{\partial E_t} > 0,$$

then, regardless of the degree of competition in the market, the market price scheduled will be:

(8) $P_t = f(R_t, F_t, OPR_t, E_t)$

where: $\frac{\partial P_t}{\partial R_t} < 0; \quad \frac{\partial P_t}{\partial F_t} > 0; \quad \frac{\partial P_t}{\partial OPR_t} < 0; \quad \frac{\partial P_t}{\partial E_t} > 0.$

The OLS regression results of relation 8 for the 1957-76 periods are:

$$(9) \qquad \ln P_t = -1.9 \ln R_t + 5.0\, F_t - 0.83 \ln OPR_t + 1.61 \ln E_t$$

(-2.7) (22.) (-4.5) (4.3)

(The price is in current dollars)

$R^2 = 0.99$

Obviously, the multiple correlations, R^2, with t-ratios for the independent variables, show that the dependence between the market price and the set of explanatory variables is substantial. Using the constant dollar, the regression results of the same period (1957-76) are:

$$(10) \qquad P_t = 181. - 0.31\, R_t + 484.0\, F_t - 9.6\, OPR_t + 0.037\, E_t$$

(0.9) (-0.9) (12.) (-5.6) (3.7)

D.W. = 2.87; $R^2 = 0.99$

The regression results of 1957-73 periods, using current dollars are:

$$(11) \qquad \ln P_t = 17.1 - 2.29 \ln R_t + 4.7\, F_t - 0.20 \ln OPR_t$$

(4.0) (-3.8) (19.) (-3.6)

$$+ 0.23 \ln E_t$$

(1.9)

D.W. = 2.65; $R^2 = 0.99$

Accordingly, the regression results in both the current and the constant dollar--for 1957-1976, 1957-1973--are consistant with the model, i.e., R_t's coefficients are negative $(\frac{\partial P_t}{\partial R_t} < 0)$, F_t's and E_t's coefficients are positive $(\frac{\partial P_t}{\partial F_t} > 0, \quad \frac{\partial P_t}{\partial E_t} > 0)$; and statistically they are significant.

In regard to energy and technical rigidity, one year may be too brief a unit of time; moreover, the effects of a cause may occur so gradually that the effect is completed after several years. For consideration of these problems--period length and lag distribution--we define new PERIOD LENGTH and consequently, new variables, with new symbols:

$$P_{5t} \equiv \frac{P_t + P_{t+1} + P_{t+2} + P_{t+3} + P_{t+4}}{5} \equiv \frac{\sum_{n=0}^{4} P_{t+n}}{5}$$

$$Q_{5t} \equiv \frac{\sum_{n=0}^{4} Q_{t+n}}{5} ; \qquad R_{5t} \equiv \frac{\sum_{n=0}^{4} R_{t+n}}{5}$$

$$OPR_{5t} \equiv \frac{\sum_{n=0}^{4} OPR_{t+n}}{5} ; \text{ etc.}$$

According to these definitions, the first period of study will be 1957-1961; the second 1958-1962, the third 1959-1963, etc. Using these variables, relation 8 becomes possible:

(13) $$P_{5t} = f(R_{5t}, F_{5t}, OPR_{5t}, E_{5t}).$$

In order to get additional information concerning time differences, a dummy variable such as D may be included. Its value will be zero for 1957-1970 and one after that period. D having been included, relation 13 becomes:

$$(14) \qquad P_{5t} = f(R_{5t}, F_{5t}, OPR_{5t}, E_{5t}, D).$$

The regression results of the above relations for OPEC (current dollar) follows:

$$(15) \qquad \ln P_{5t} = \underset{(2.1)}{72.} - \underset{(-5.5)}{12.2} \ln R_{5t} + \underset{(5.1)}{1.3} F_{5t} - \underset{(-0.6)}{0.8} \ln OPR_{5t} + \underset{(0.4)}{1.1} \ln E_{5t} + \underset{(3.7)}{0.38} D$$

$$D.W. = 1.82; \; R^2 = 0.99$$

The regression results of relation 14 when price is measured in constant dollars are:

$$(16) \qquad \ln P_{5t} = \underset{(1.7)}{33.} - \underset{(-4.4)}{5.8} \ln R_{5t} + \underset{(5.2)}{0.8} F_{5t} - \underset{(-0.9)}{0.7} \ln OPR_{5t} + \underset{(0.6)}{1.0} E_{5t} + \underset{(3.2)}{0.19} D$$

These results also confirm the idea that the market price is negatively related to the stock of proved reserve and positively related to the expected discounted future price.

III. TESTING THE HYPOTHESIS

Little attention has been paid to the degree of competition of the international crude oil market because there is little need for it. The mine owner, or a producer country, has a user cost function which works as a supply schedule for him, or her. Any change of the degree of competition may shift the curve or it may change the shape or slope of the user cost. Nevertheless, the rate of production, or the market price, will be determined by the intersection of the supply function, P_{st}, with the demand function, P_{dt}. If the market is in perfect competition, which is rare, there will be infinitive intersections of the supply with the demand function, P_{dt}. In this case, the mine owner is indifferent to producing too little or too much.

To test the hypothesis that P_{st} (the user cost schedule) is the quasi supply function for OPEC, it is adequate to find the intersection of this function with the demand schedule and to compare this equilibrium with the actual market price. However, it is not the rate of production, Q_t, but rather the market price, P_t, in which we are interested and the variation of which we seek to explain. Therefore, we have preferred to estimate structural equations in terms of rate of production, Q_{st}, and consumption, Q_{dt}, in order to find equilibrium price.

Ordinary least squares multiple regression equations for the dependent variables, Q_{st} (rate of production) and Q_{dt} (rate of consumption) for 1975-76 are:

(17) $$\ln Q_{st} = -6.5 + 0.34 \ln P_t + 0.61 \ln R_t - 1.68 F_t$$
$$(-0.8) \quad (1.62) \quad (1.45) \quad (-1.8)$$
$$+ 1.08 \ln OPR_t$$
$$(23.)$$

The price in current dollars

D.W. = 1.14

$R^2 = 0.99$

(18) $$\ln Q_{dt} = -17.8 - 0.053 \ln P_t + 2.28 \ln E_t$$
$$(-39.) \quad (-3.0) \quad (38.)$$

The price in current dollars

D.W. = 0.99

$R^2 = 0.99$

At equilibrium when $Q_{st} = Q_{dt}$, the market price will be;

(19) $$.34 \ln P_t + 0.053 \ln P_t = 6.5 - 17.8 + 1.68 F_t - 1.08 \ln OPR + 2.28 \ln E_t - 0.61 \ln R_t$$

and:

(20) $$\ln P_t = -28.067 + 5.687 \ln E_t - 1.52 \ln R_t + 4.1 F_t - 2.7 OPR_t$$

If we substitute the actual value of E_t, R_t, F_t and OPR_t for 1960, 1970, 1973 and 1976 in equation 20, the estimated actual market price will be:

Table 12

Actual and Estimated Prices of 1960, '70, '73, and 1976

	1960	1970	1973	1976
Actual P_t \$	0.81	0.95	2.11	9.50
Estimated P_t \$	0.81	1.10	1.99	9.40

Thus the results are satisfactory.

Equation 3 (in which the user cost is the dependent variable with $R^2 = 0.997$), equation 9 (in which market price is the dependent variable with $R^2 = 0.995$), and finally Table 12 (which is the result of the intersection of Q_{st} and Q_{dt}) strongly indicate that for the period of study Q_{st} and P_{st} have the properties of a supply schedule; therefore, it is logical to call these functions "quasi supply" or simply "supply" functions.

IV. PREDICTING

The OLS regression results when the dependent variables are Q_s, Q_d, P_s and P have confirmed the model and are consistent with each other. Also, for all the regressions, a high R^2 indicates a very low deviation between the estimated and actual values, see Table 12. Nevertheless, since the period of study is 1957-1976, it is impossible to test the predicting power of the model. One possible solution is the selection of a period of study several years prior to 1976. The period of 1957-73 is an appropriate selection for this purpose since it does not include the so-called "quadruple price increase" of 1973-74 and its predicted price may be compared with the actual prices of 1974 and thereafter. The following is the regression results for P_t for the 1957-73 period (price in current dollars).

$$\text{(21)} \qquad \ln P_t = \underset{(4.0)}{17.17} - \underset{(-3.9)}{2.3 \ln R} + \underset{(19.5)}{4.7\, F_t} - \underset{(-3.7)}{0.2 \ln OPR_t}$$

$$\underset{(1.90)}{0.23 \ln E_t}$$

$$D.W. = 2.64; \quad R^2 = 0.99$$

The multiple correlation coefficient is close to one, i.e., the estimated price and market price for 1957-73 are very close; moreover, if one substitutes the actual value of explanatory variables for 1974, 1975, and 1976 in the equation, the predicted price will be still close to the actual market price. For example, according to this equation for 1974, the predicted price is $8.56 and the actual price in 1974 was $8.90. For 1976 there is a larger gap: the predicted price is only $7.07 (which is lower than the predicted price of $8.56 for 1974) while the actual market price of 1976 is higher than the actual market price of 1974 at $9.50. At first view, it would seem that this equation cannot predict the future, since it predicts that the 1976 price would be lower than the 1974 price while the actual market price of 1976 proves to be higher than the actual market price of 1974.

If the rate of inflation were low and negligible, we could not accept this equation as a tool for predicting the future prices, i.e., there would be no reason to infer its predicting power; however, for the last five years, the rate of inflation has not been negligible. In this case, the rate of inflation may be argued, for it is extremely difficult to construct an acceptable price index. Nevertheless, by any account, $9.50 in 1976 had lower purchasing power than $8.90 in 1974.

Having presented an estimation of the reduced-form equation, we may now offer the OLS multiple regression results for the dependent variables Q_{st} (rate of production) and Q_{dt} (rate of consumption) for 1957-73 in order to derive and estimate equilibrium price, P_t, and then examine the predicting power of the structural equations. The following are the quasi supply and the quasi demand functions regarding international crude oil market for the period of 1957-73.

(6) $$Q_{st} = f(P_t, R_t, F_t, OPR_t)$$

(7) $$Q_{dt} = f(P_t, E_t)$$

(22) $$\ln Q_{st} = -46.8 + \underset{(2.2)}{2.2} \ln P_t + \underset{(2.8)}{5.6} \ln R_t - \underset{(2.0)}{10.6}\; F_t \quad (-2.8)$$

$$+ 1.2 \ln OPR_t$$
$$(14.7)$$

D.W. = 2.08; $R^2 = 0.99$

(23) $$\ln Q_{dt} = - 17.85 - 0.06 \ln P_t + 2.2 \ln E_t$$
$$(-37.) \qquad (-1.0) \qquad (29.)$$

D.W. = 0.67; $R^2 = 0.99$

(24) $$\ln P_t = 12.4 + 0.98 \ln E_t - 2.4 \ln R_t + 4.5 F_t - 0.5 \ln OPR_t$$

Table 13 shows actual and estimated (or predicted) prices according to equation 24.

Table 13

Actual, Estimated, and Predicted Prices:
Regression Method is OLS

Year	Actual $	Predicted (Estimated) $
1960	0.82	0.82
1970	0.95	0.97
1973	2.12	2.11
1974	8.93	8.20
1976	9.50	7.34

Usually the method of two stages least squares (TSLS) is preferred, for the estimation of the structural equation, to ordinary least squares. The following are the regression results for relation 6 and 7 where the method of estimation is TSLS. The period to be considered is 1957-73 (prices in current dollars).

(25) $$\ln Q_{st} = -\underset{(-2.)}{125.7} + \underset{(2.1)}{5.7 \ln \hat{P}_t} + \underset{(1.9)}{15. \ln R_t} - \underset{(-2.1)}{26. F_t}$$

$$\underset{(5.8)}{1.6 \ln OPR_t}$$

D.W. = 3.29; $R^2 = 0.99$

(26) $$\ln Q_{dt} = -\underset{(-37.)}{17.87} - \underset{(-1.0)}{0.067 \ln \hat{P}_t} + \underset{(29.7)}{2.2 \ln E_t}$$

D.W. = .67; $R^2 = 0.99$

At equilibrium where $Q_{st} = Q_{dt}$, the equilibrium price is:

$$(27) \qquad \ln \hat{P}_t = 18.5 + 0.4 \ln E - 2.7 \ln R + 4.5 F_t - 0.28 \ln OPR_t$$

Estimated (and predicted) price for different years compared to their actual price are given in table 14.

Table 14

Actual, Estimated, and Predicted Price:
Regression Method is TSLS

Year	Actual $	Estimated (Predicted) $
1957	0.82	0.84
1970	0.95	0.96
- - -	- - -	- - -
1974	8.93	8.21
1976	9.50	7.11

Note 3: Considering 1973 as a base year for the wholesale price index of the United States (1973=100), the wholesale price for 1976 is 134.90. That is, ($7.11) (1.349) = $9.59, i.e., the predicted and actual prices for 1976 are very close.

Note 4: The nominal 1976 price of crude oil is more than 400% of the 1973 price level. Yet, according to table 14 and note 3, relation 27 not only could predict the increase but it also could explain it; i.e., 80% of the price increase has been contributed by the increase of F_t (inflation is included) and the rest of the explanatory variables

(R_t, E_t and OPR_t) are responsible for only 20% of the price increase (15% contributed by a decrease of R_t and 5% for changes of E_t and OPR_t).

Note 5: The definition of F_t, its highest t-ratio for the regression results, and its highest share in contributing to the explanation of price changes, may cause an illusion that it is statistically a dominant variable. Doubtless, a careful reader will not be affected by the illusions, because:

(1) a high contribution of F_t for the price changes of the recent years simply resembles the events which we mentioned in Chapter 2, i.e, the scarcity rent of oil moving from negligible to significant. Also, part of the contribution may be counted for inflation.

(2) Whenever the length of a period is 5 years instead of one year, the t-ratio for F_{5t} is not the highest among the explanatory variables.

(3) If we eliminate F_t from the explanatory variables, the regression results have, of course, lower R^2 but the results are still consistant with the model, i.e.,

$$\frac{\partial P_t}{\partial R_t} < 0; \quad \frac{\partial P_t}{\partial E_t} > 0; \quad \frac{\partial P_t}{\partial PL_t} > 0$$

(28) $$P_t = -\,0.394\,R_t - 13.75\,OPR_t + 0.05E_t + 1.91\,PL_t$$

$$\qquad (-3.2) \qquad (-2.9) \qquad (2.0) \qquad (6.6)$$

$R^2 = 0.90$

Period of study is 1957-76;

Prices are in constant $

Relation 28 is similar to relation 9, except that in relation 28 F_t (and inflation effects) have been excluded but PL_t has been included.

APPENDIX TO CHAPTER 3

TABLES 1-10

THE REGRESSION RESULTS

TABLE 1

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_t + a_3 F_t + a_4 \ln OPR_t + a_o$$

(1) Data are from OPEC.

(2) The regression method is OLS.

(3) Whenever OPR_t has not been included in the list of explanatory variables, its corresponding coefficient is blank.

1. Period of Study 2. Prices	Regression Statistics		Coefficients				Constant
	D.W.	R^2	a_1	a_2	a_3	a_4	a_o
1. 1957-76 2. Current $	2.03	0.9979	0.43 (1.6)	-4.8 (-5.6)	4.4 (20.0)	-0.61 (-2.2)	35.1 (5.7)
1. 1957-76 2. Current $	1.86	0.9972	-0.16 (-4.8)	-5.4 (-6.1)	4.3 (18.0)	-	38.5 (6.9)
1. 1957-73 2. Current $	3.29	0.9990	+0.17 (2.8)	-2.7 (-6.1)	4.6 (23.0)	-0.28 (-4.3)	21.8 (7.8)
1. 1957-73 2. Current $	1.76	0.9975	-0.09 (-7.0)	-2.9 (-4.2)	4.5 (15.0)	-	22.5 (5.3)
1. 1957-76 2. Constant $	1.99	0.9841	0.55 (1.6)	-1.38 (-1.25)	2.4 (8.6)	-0.75 (-2.1)	14.2 (2.1)
1. 1957-73 2. Constant $	1.93	0.8014	0.29 (1.0)	-1.1 (-0.6)	1.5 (1.7)	-0.45 (-1.3)	12.4 (0.97)

TABLE 2

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_2 + a_3 F_t + a_4 \ln OPR_t + a_o$$

(1) Data are from IRAN.

(2) The regression method is OLS.

(3) Whenever OPR_t has not been included in the list of explanatory variables, its corresponding coefficient is blank.

1. Period of Study 2. Prices	Regression Statistics D.W.	R^2	Coefficients a_1	a_2	a_3	a_4	Constant a_o
1. 1957-76 2. Current $	1.32	0.9957	0.24 (1.3)	-3.9 (-5.0)	4.1 (15.0)	0.07 (0.3)	21.4 (5.7)
1. 1957-76 2. Current $	1.33	0.9956	-0.18 (-4.9)	-3.8 (-5.7)	4.1 (16.0)	-	21.0 (7.2)
1. 1957-73 2. Current $	0.94	0.9885	-0.15 (-0.98)	-1.6 (-1.8)	4.6 (12.8)	0.08 (0.4)	11.25 (2.9)
1. 1957-73 2. Current $	0.87	0.9883	-0.09 (-2.3)	-1.5 (-1.8)	4.6 (14.0)	-	10.9 (3.0)
1. 1957-76 2. Constant $	2.59	0.9928	-9.0 (-0.9)	-2.7 (-2.7)	334.0 (16.0)	-1.6 (-2.4)	340.0 (4.0)
1. 1957-73 2. Constant $	1.73	0.9759	-	-0.2 (-0.19)	400.0 (16.0)	-1.7 (-3.4)	133.0 (1.3)

TABLE 3

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_t + a_3 F_t + a_4 \ln OPR_t + a_o$$

(1) The regression method is TSLS.

(2) Prices are in current \$.

Country	Regression Statistics	Coefficients				Constant
	R^2	a_1	a_2	a_3	a_4	a_o
OPEC	0.9978	0.21 (0.55)	-5.08 (-5.04)	4.3 (19.0)	-0.38 (-0.98)	36.6 (6.5)
Iran	0.9932	-0.76 (-1.86)	-5.4 (-3.9)	3.7 (9.4)	0.70 (1.41)	25.9 (5.2)
Iraq	0.9518	-1.44 (-1.01)	-7.4 (-1.15)	5.8 (7.9)	-1.10 (-.32)	30.8 (1.35)
Kuwait	0.9958	-0.2 (-.22)	-7.06 (-1.15)	4.5 (6.9)	-0.37 (-.0.37)	35.6 (1.22)
Saudi Arabia	0.9944	0.65 (1.73)	-3.03 (-1.74)	4.1 (13.0)	-0.91 (-2.3)	21.6 (2.79)
Venezuela	0.9969	-0.67 (-1.81)	-0.12 (-0.19)	4.6 (18.7)	0.15 (0.52)	4.68 (1.73)

TABLE 4

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_t + a_3 F_t + a_4 \ln OPR_t + a_o$$

(1) The regression method is TSLS.

(2) Prices are in constant $.

Country	Regression Statistics		Coefficients				Constant
	D.W.	R^2	a_1	a_2	a_3	a_4	a_o
OPEC	1.98	0.9840	0.64 (1.31)	-1.27 (-1.07)	2.45 (8.5)	-0.84 (-1.69)	13.62 (1.91)
Iran	-	0.9875	-0.09 (-0.34)	-1.27 (-1.42)	2.11 (8.48)	-0.71 (-0.2)	10.26 (3.25)
Iraq	-	0.9698	-0.36 (-0.77)	-3.41 (-1.48)	2.98 (10.77)	-0.3 (-2.3)	17.46 (2.12)
Kuwait	2.12	0.9729	-0.22 (-0.27)	-0.86 (-0.15)	2.3 (3.9)	-0.06 (-0.07)	8.2 (0.3)
Saudi Arabia	2.14	0.9807	-0.08 (-0.26)	-1.8 (-1.2)	2.5 (9.4)	-0.14 (-0.43)	13.8 (2.0)
Venezuela	1.98	0.9833	0.12 (0.3)	-0.64 (-0.93)	2.5 (9.6)	-0.39 (-1.2)	7.7 (2.6)

TABLE 5

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_t + a_3 \ln F_t + a_o$$

(1) The regression method is OLS.

(2) Prices are in current $.

Country	Regression Statistics		Coefficients			Constant
	D.W.	R^2	a_1	a_2	a_3	a_o
Iran	1.33	0.9956	-0.18 (-4.9)	-3.8 (-5.7)	4.13 (16.8)	21.0 (7.2)
Iraq	1.30	0.9869	0.01 (0.05)	0.9 (0.6)	5.6 (19.7)	0.8 (0.1)
Kuwait	1.70	0.9952	-0.4 (-3.9)	-4.0 (-3.6)	4.4 (16.0)	52.0 (4.0)
Saudi Arabia	1.42	0.9950	-0.19 (-3.9)	-5.5 (-4.6)	4.3 (16.0)	70.0 (4.9)
Venezuela	1.58	0.9968	-0.5 (-4.1)	-0.4 (-2.8)	4.6 (19.7)	12.7 (5.4)

TABLE 6

$$\ln P_{st} = a_1 \ln Q_t + a_2 \ln R_t + a_3 F_t + a_o$$

(1) The regression method is OLS.

(2) The prices are in constant $

Country	Regression Statistics		Coefficients			Constant
	D.W.	R^2	a_1	a_2	a_3	a_o
Iran	2.74	0.9885	-0.16 (-6.3)	-1.51 (-3.3)	2.06 (12.2)	11.09 (5.5)
Iraq	0.99	0.986	0.06 (0.39)	2.3 (2.08)	3.14 (14.2)	-3.8 (-0.97)
Kuwait	1.87	0.9730	-0.17 (-1.39)	0.47 (0.40)	2.52 (8.7)	0.23 (0.01)
Saudi Arabia	2.26	0.9817	-0.22 (-5.1)	-2.35 (-2.19)	2.58 (10.8)	33.7 (2.6)
Venezuela	1.80	0.9835	-0.36 (-2.8)	0.14 (0.87)	2.50 (10.0)	5.7 (2.3)
OPEC	1.83	0.9792	-0.17 (-4.2)	-2.18 (-1.91)	2.31 (7.6)	18.3 (2.5)

TABLE 7

$$A: \ln P_t = c_1 \ln R_t + c_2 \ln F_t + c_3 \ln OPR_t + c_4 \ln E_t + c_o$$

$$B: P_t = c_1 R_t + c_2 F_t + c_3 OPR_t + c_4 E_t + c_o$$

(Data are from OPEC)

1. Period of Study 2. Equation 3. Prices	Regression Statistics D.W.	R^2	Coefficients c_1	c_2	c_3	c_4	Constant c_o
1. 1957-76 2. Eq. A 3. Current $	-	0.9951	-1.19 (-2.69)	5.01 (22.0)	-0.83 (-4.5)	1.62 (4.3)	-
1. 1957-73 2. Eq. A 3. Current $	2.64	0.9987	-2.29 (-3.8)	4.7 (19.0)	-0.20 (-3.6)	0.23 (1.90)	17.1 (4.0)
1. 1957-70 2. Eq. A 3. Current $	2.77	0.9765	-2.7 (-5.8)	1.7 (1.8)	-0.13 (-2.8)	0.26 (2.8)	19.3 (5.9)
1. 1957-76 2. Eq. B 3. Constant $	2.87	0.9905	-0.31 (-0.88)	484.0 (12.0)	-9.6 (-5.6)	0.037 (3.7)	181.0 (0.92)
1. 1957-73 2. Eq. B 3. Constant $	2.03	0.8249	-0.62 (-1.35)	262.0 (2.4)	-6.3 (-2.0)	0.024 (1.7)	362.0 (1.55)

TABLE 8

A: $\ln Q_{st} = a_1 \ln P_t + a_2 \ln R_t + a_3 F_t + a_4 \ln OPR_t + a_o$

B: $Q_{st} = a_1 P_t + a_2 R_t + a_3 F_t + a_4 OPR_t + a_o$

(Data are from OPEC)

1. Period of Study 2. Equation 3. Regression Method 4. Prices	Regression Statistics D.W.	R^2	Coefficients a_1	a_2	a_3	a_4	Constant a_o
1. 1957-76 2. Eq. A 3. OLS 4. Current $	1.14	0.9961	0.34 (1.62)	0.61 (0.45)	-1.68 (-1.78)	1.08 (23.0)	-6.5 (-0.78)
1. 1957-73 2. Eq. A 3. TSLS 4. Current $	3.28	0.9937	4.76 (2.3)	12.8 (2.0)	-22.0 (-2.4)	1.53 (7.4)	-103.5 (-2.2)
1. 1957-73 2. Eq. A 3. OLS 4. Current $	2.08	0.9965	2.26 (2.81)	5.6 (2.0)	-10.6 (-2.8)	1.28 (14.7)	-46.8 (-2.2)
1. 1957-73 2. Eq. B 3. TSLS 4. Constant $	-	0.9967	0.031 (2.2)	0.008 (0.43)	-5.8 (-1.4)	0.42 (18.4)	-8.0 (-0.74)

TABLE 9

$$Q_{dt} = b_1 P_t + b_2 E_t + b_3 PL_t + b_o$$

1. Period of Study 2. Regression Method 3. Prices	Regression Statistics R^2	Coefficients b_1	 b_2	 b_3	Constant b_o
1. 1957-76 2. TSLS 3. Current $	0.9906	-0.0017 (-1.37)	0.0019 (15.4)	0.0066 (1.29)	-6.14 (-16.0)
1. 1957-76 2. OLS 3. Current $	0.9906	-0.0013 (-1.15)	0.00199 (16.4)	0.0050 (1.07)	-6.1 (-16.1)
1. 1957-76 2. OLS 3. Constant $	0.9924	-0.0055 (-2.2)	0.0019 (18.0)	0.0147 (2.29)	-6.2 (-21.8)
1. 1957-73 2. TSLS 3. Constant $	0.9694	-0.1045 (-10.6)	0.0015 (8.2)	0.0675 (5.2)	-
1. 1957-73 2. OLS 3. Constant $	0.9707	-0.0972 (-10.4)	0.0015 (8.5)	0.0605 (4.88)	-

TABLE 10

$$A: \ln Q_{dt} = b_1 \ln P_t + b_2 \ln E_t + b_o$$

$$B: Q_{dt} = b_1 P_t + b_2 E_t + b_o$$

1. Period of Study 2. Regression Method 3. Equation 4. Prices	Regression Statistics D.W.	R^2	Coefficients b_1	b_2	Constant b_o
1. 1957-76 2. OLS 3. A 4. Current $	0.99	0.9940	-0.053 (-2.98)	2.28 (38.0)	-17.8 (-39.3)
1. 1957-76 2. TSLS 3. A 4. Current $	1.00	0.9940	-0.055 (-3.0)	2.28 (38.0)	-17.8 (-39.0)
1. 1957-76 2. OLS 3. B 4. Constant $	-	0.9900	-0.0006 (-0.45)	0.0021 (30.9)	-6.2 (-19.2)
1. 1957-73 2. TSLS 3. A 4. Current $	0.67	0.9932	-0.067 (-1.01)	2.29 (29.0)	-17.8 (-37.7)
1. 1957-73 2. OLS 3. A 4. Current $	0.67	0.9932	-0.063 (-0.95	2.29 (29.0)	-17.8 (-37.7)
1. 1957-73 2. OLS 3. B 4. Constant $	-	0.9208	-0.0649 (-6.2)	0.0021 (11.6)	-

FOOTNOTES

[1]Whenever the competition is perfect, marginal cost of a commodity is also its supply curve; while MC is not the supply function in the case of imperfect competition. Nevertheless, the rationale for using the term "supply function" for the international crude oil is the following (A and/or B):

(A) As my distinguished professor, Michael Grossman, has suggested: although a monopolist does not have a supply curve, one can rationalize the estimates by appealing to the constant elasticity of marginal cost and marginal revenue functions, i.e.:

(1) $\ln MC = a_0 + e^{-1} \ln Q + a_2 \ln z$

(2) $\ln MR = b_0 - \varepsilon^{-1} \ln Q + b_2 \ln y$

Where

$\ln z$ = vector of MC variables;

$\ln y$ = vector of demand variables;

(3) in equilibrium: $\ln MC = \ln MR$

(4) $\ln MR \equiv \ln P + \ln(1 - \frac{1}{\varepsilon})$

Therefore

(5) $\ln P = a_0 - \ln (1 - \frac{1}{\varepsilon}) + e^{-1} \ln Q + a_2 \ln z$

Relation (1) is the marginal cost curve, while relation (5) is the (inverted) quasi supply function.

(B) It has been shown in chapter one that "as far as a resource is subject to the economics of exhaustible resources, its average user cost is--regardless of the degree of competition in the market--its supply function as well." At the same time, to remind the reader of the peculiarities of the economics of exhaustible resources, the prefix "quasi" has been used for the supply function.

[2]Numerous demand functions can be estimated for international crude oil because there are numerous prices for the resource. It has been shown in this chapter why and how the price a country pays for a barrel of crude oil is considerably higher than the amount which a producer country receives for the same barrel. To standardize the unit of measurement, we use the price which a producer receives as the market

price and demand has been estimated as a producer country sees it, therefore it is called the "quasi" demand function.

[3]Paul Bradley, The Economics of Crude Oil Production, p. 53.

[4]Ibid., p. 72.

[5]M. A. Adelman, The World Petroleum Market, p.76.

[6]Ibid., p. 77.

[7]Ibid., p. 40

[8]The sources of the data which have been used in this study have been mentioned on page 94, footnote 18.

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