THE IRRELEVANCE OF *OPEC*: PROPERTY RIGHTS AND IMPLICIT DISCOUNT RATES IN THE WORLD OIL MARKET

Robert E. Marks
Peter L. Swan

Australian Graduate School of Management
University of New South Wales
P.O. Box 1
Kensington NSW 2033
Australia

Revised March 1988

An earlier version of this paper was presented at the North American meetings of the International Association of Energy Economists, MIT, November 1986 (Marks & Swan 1987). A later version of Section 3 was published in (Marks & Swan 1993).

THE IRRELEVANCE OF *OPEC*: PROPERTY RIGHTS AND IMPLICIT DISCOUNT RATES IN THE WORLD OIL MARKET

Robert E. Marks
Peter L. Swan

ABSTRACT

The recent slump and partial recovery of the world oil price has again focused attention on the structure of the world oil market, and the influence of OPEC on oil pricing. As Griffin has recently summarized, there are four theories vying for dominance: (1) the cartel model, in which OPEC, perhaps as a price leader, exercised market power by raising the price in 1973/74 and 1979/80; (2) the revenue-target model, in which short-run considerations result in oil producers aiming to maintain net revenue targets rather than to maximize net wealth dynamically; (3) the simple Hotelling model, in which the oil price rose over time in response to increasing scarcity; and (4) the property-rights model, in which the two price increases were a result of the change in control over oil production from the oil companies to the oil-producing countries, and hence a change from high rates of time preference (the discount rate) to low rates on the part of the production decision-makers.

The purpose of this paper is to use a simple model which relates the discount rate, the reserves/production ratio, and the price elasticity of demand to derive implicit discount rates from the early 1950s to the mid-1980s. This enables confirmation that the price rises of the 1970s were accompanied by a drop in discount rates, as predicted by the property-rights model. The high discount rates for the Middle East producers from 1956 to 1974 imply disequilibrium in the world oil markets, in which technical rather than economic aspects dominate. We conclude by discussing the implications of our findings for future oil prices.

THE IRRELEVANCE OF *OPEC*: PROPERTY RIGHTS AND IMPLICIT DISCOUNT RATES IN THE WORLD OIL MARKET

Robert Marks
Peter Swan †

1. Introduction

The recent volatility in the world price of oil has renewed interest in theories of the structure of the world oil market in general and the rôle of OPEC in particular. The first oil shock of 1973/74 was soon followed by theories of OPEC as a "price leader," in which OPEC as the "dominant firm" maximized its profit subject to the passive competition of the non-OPEC, price-taking "competitive fringe." More sophisticated models of the market, in which intertemporal trade-offs were allowed, followed.

At the same time others were arguing that since oil was an exhaustible resource, the pre-embargo oil price understated its scarcity: if the replacement (or scarcity) cost of the oil was not reflected in its price, its rate of use would be excessive, leading to premature exhaustion of stocks and an implicit subsidy of the present from the future. The post-embargo price of oil, so advocates of the "competitive" pricing theory argued, was a better reflection of its scarcity.[1]

The "property rights" theory is related to the competing theories of the OPEC cartel and of oil as an exhaustible resource, but does not require the market power of the first and pays heed to the change in the *control* of the production and pricing of oil which have occurred since the mid-1950s.[2] This paper examines evidence for the property-rights theory through changes in the implicit discount rate for the world oil market.

Table 1 (from Griffin and Steele, 1986) shows the change in *ownership* of oil production in OPEC countries, and may under-estimate the degree of control (although ownership is neither sufficient nor necessary for control). As Blair (1976, p.97) reports from the *Petroleum Economist*: "Attempts at nationalization over the years were

---

† The Australian Graduate School of Management, University of New South Wales, PO Box 1, Kensington, NSW 2033, Australia. We should like to thank Fiona Beach of the BP Australia Library for her assistance in providing data, and Sumner La Croix and Robert Kohn for their helpful comments.

1. A general-equilibrium model of exhaustible oil (Chichilnisky, Heal and Sepahban, 1983) predicts the possibility of a sharp rise in world price following a long period of falling real prices—such as seen in 1973/74—but cannot predict the price slump of 1986.
2. OPEC was formed in 1960 by Iran, Iraq, Saudi Arabia, and Kuwait, and the successive entry of other exporting countries provides a measure of the increasing effectiveness of the shift in control from the oil companies to national governments: Qatar in 1961, Indonesia and Libya in 1962, Abu Dhabi in 1967, Algeria in 1969, Nigeria in 1971, and finally Ecuador and Gabon in 1973.

generally not successful unless and until agreement was reached with the concessionary companies [almost always the oil majors] to bring the state's activities within the framework of the existing world system."

TABLE 1. Percentage of Government-Owned Oil Production for Selected Years in OPEC Countries

Country	1970	1972	1974	1976	1978	1980
Saudi Arabia	0.9	0.7	58.5	58.7	58.7	97.7
Iran	4.5	5.0	96.2	96.2	94.6	100
Kuwait	1.2	1.2	55.1	90.6	94.1	90.6
Iraq	0	53.8	77.2	100	100	100
Libya	0	3.6	60.7	64.2	65.7	67.5
U.A.E.	0	0	49.5	62.1	64.4	64.4
Venezuela	1.2	1.9	2.5	100	100	100
Qatar	0	0	60.0	78.5	99.4	100
Nigeria	0	0	54.9	55.1	54.9	71.1
Indonesia	11.7	16.2	30.5	36.6	44.6	45.7
Algeria	14.6	76.9	88.2	90.5	89.1	93.7
Ecuador	—	1.3	25.4	25.5	62.9	62.7
Gabon	0	0	0	0	0	0

Source: Griffin and Steele (1986)

The increase in control over oil production by the producing governments had been preceded by a fall in the importance of the seven oil "majors" in the world oil market: Adelman (1972) reports that from a total market share (excluding North America and the communist countries) of 98.3% in 1930, their share fell to 89.0% in 1957, and to 76.1% in the first half of 1969.

Table 2 (from Rustow and Mugno, 1976) shows the share of the oil majors, the independents, and the government oil companies in OPEC oil production.

Despite the increase of government companies' share over the period 1970–1974, the oil companies still had control over the production of oil, except in Venezuela, Kuwait, and Libya (Rustow and Mugno, 1976). This occurred under "buy-back" provisions (in Saudi Arabia, Kuwait, Qatar, and Abu Dhabi) or long-term supply agreements (in Iran). In Venezuela, Kuwait, and Libya, government production limits at times restricted output.

Section 2 puts forward the property rights theory. Section 3 establishes the relationship which must hold between the discount rate and the reserves/production ratio under competitive market conditions. Section 4 relaxes some of these conditions, and examines what each producer or region will tend to do given the nature of property rights, the overall market condition and their own circumstances. Section 5 examines

TABLE 2. Company Shares of OPEC Oil Production

	1961	1965	1970	1971	1972	1973	1974
Oil majors[a]	88.4	84.4	77.0	78.4	76.6	48.0	31.6
Independents[b]	10.9	14.7	20.7	17.6	15.2	9.8	8.9
Government companies[c]	0.7	1.0	2.3	3.9	8.3	42.3	59.6

Notes: *a* Exxon, BP, Shell, Gulf, Texaco, SoCal, Mobil
b CFP, and all other non-OPEC companies
c OPEC national oil companies
Source: Rustow and Mugno (1976)

the empirical evidence in more detail and establishes the path of the overall discount rate. Conclusions are presented in Section 6.

2. The Property Rights Theory

The property-rights theory postulates that as the oil majors saw the control over production decisions slipping from their grasp with the rise in the power of oil exporting countries, they increased their production levels in order to maximize the present value of their profit stream, given an implicit discount rate which was very high due to the threat of nationalization. The aggregate effect of this was to depress prices below the levels that would have obtained without the higher rates of oil production.

By 1973 the relatively low prices of oil meant that oil's share of total energy use had risen from 34% in 1960 to 46% by 1973 (Griffin and Steele, 1986). At the same time, control of production decisions had begun to move decisively towards the exporting countries. The embargo against the US and the Netherlands at the time of the Yom Kippur War provided the trigger for the exporting countries to realize their power and effectively to change ownership. As Johany (1980, p.44) put it (his emphasis):

> "*The oil producers* [the exporting countries] *decided to determine the price of their oil unilaterally rather than through negotiations* with the oil companies as had been done in the past. Once the host countries became the ones who decided the rate of oil output and its price, the rôle of companies had been essentially reduced to that of contractors. That amounted to a de facto nationalization of the crude-oil deposits."

The basis of the argument is that while governments are prone to take short-term perspectives, nonetheless the time horizons of the oil majors were even more limited. Hence, with actual or de facto nationalisation, governments would slow down the growth of oil extraction. Moreover, given the lack of diversification of exports of many oil-exporting countries, there was an incentive for them to husband their precious oil reserves. In aggregate this behavior would lead to a rise in the price of oil and hence in the value of the oil reserves. [Indeed, the revenue-target theory (Ball and Marks, 1986) suggests that their primary goal was to generate a target level of net revenue from oil

sales.]

The property-rights theory of the world oil market explains the rise in prices in 1973/74 (the first oil shock) in terms of this change in control over the production (and pricing) decisions. In economic terms, the change in control is associated with a change in discount rates: the short horizons of the oil companies, anticipating impending loss of control, correspond to discount rates higher than those of the exporting countries—who gained control at the time of the first oil shock—with their longer perspectives. The following model will allow us to formalize this description.

The net price (or scarcity rent) $Q(t)$ of the oil at time t is defined as

$$Q(t) \equiv P(t) - C(t),$$

where $P(t)$ and $C(t)$ are the unit price and the average cost of extracting the oil in period t. The Hotelling Rule tells us that under intertemporal asset equilibrium with no uncertainty the scarcity rent of an exhaustible resource grows at the discount rate $r(t)$:

$$\dot{Q}(t)/Q(t) = r(t).$$

If the discount rate r is believed to be constant over the interval $(t, t + \delta t)$, then the believed competitive path of the scarcity rent is given by

$$Q(t + \delta t) = Q(t)\ e^{r\,\delta t}.$$

We assume that oil is an exhaustible resource, even if the ultimate size of the reserves is not yet known. The expropriation of the firm's property rights over the oil (the control over production and pricing conditions) through direct or indirect nationalization is modeled as a Poisson process with intensity p, which implies that the time before nationalization occurs is a random variable with mean $1/p$ and variance $1/p^2$, or that the probability of its occurrence is p per unit time.

Theorem 1: The effect of the risk of nationalization of an exhaustible resource (oil) is to add a risk premium p to the "riskless" discount rate r of the oil companies.

Proof: For a risk-neutral firm, the expected return, given the perceived risk of nationalization, must be competitive. By the Poisson process assumption, the probability that the firm is *not* nationalized in the next (small) interval δt is given by $e^{-p\,\delta t}$, and the expected net price at time $t + \delta t$ given the known net price $Q(t)$ at time t is

$$E[Q(t + \delta t)] = e^{-p\,\delta t}\ Q(t)\ e^{u\,\delta t} + (1 - e^{-p\,\delta t})\ 0,$$

where the random variable $Q(t + \delta t)$ is the stochastic net price at time $t + \delta t$, where u is the discount rate given the risk of nationalization, and where the net price for the firm at time $t + \delta t$ given that nationalization has occurred in the period $(t, t + \delta t)$ is zero. But risk-neutral companies will supply oil only if

$$E[Q(t + \delta t)] = Q(t)\ e^{r\,\delta t}$$

or, from above, only if

$$e^{-p\delta t}\, Q(t)\, e^{u\delta t} = Q(t)\, e^{r\delta t},$$

which is true only if

$$u = r + p$$

Thus, with a probability of nationalization of p per unit time, the net price must grow at the rate $r + p > r$ for asset-market equilibrium, which is equivalent to a higher discount rate. □

Thus, if the market rate of interest is 10% per annum, and the probability of "nationalization" in the next year is 0.25, the companies' effective discount rate is 35% per annum. As Johany argues (1982, p.135), "The net effect of uncertainty of property rights is to increase the companies' discount rate, which will lead them to increase their oil outputs by a greater rate than they otherwise would if there were no risks of expropriations."[3] Adelman's (1982) slightly more cumbersome result, that $u = (r + p)/(1 - p)$, is less appealing.

The proof of Theorem 1 relies on the asset-market equilibrium condition.[4] But with a fear of expropriation such an equilibrium—with the price of the exhaustible resource rising at the rate $u = r + p > r$—will not occur: instead there will be a disequilibrium with excessive production of the resource, and the price will rise at less than the interest rate r. The discount rate u is a measure of the lack of importance of the future to the oil companies who expect expropriation, not the Hotelling growth rate, which equals "riskless" r in equilibrium.

This disequilibrium is likely to last until one of two events occurs: (1) the feared expropriation takes place—indeed, the companies' expectations of expropriation may be self-fulfilling if the exporting countries take action to halt the companies' too-rapid depletion of their oil reserves; or (2) the depletion of oil reserves results in the price eventually rising to a rate of growth at which the companies are indifferent between pumping or not, that is, in which the expected capital gains adequately reward them for the risk of expropriation—equilibrium given the fear of expropriation. We argue below that a period of disequilibrium from the mid-1950s onwards was eventually ended by expropriation.

---

3. Johany makes the further point that even if the companies had faced no immediate threat to their property rights, had ownership reverted to them they would still have produced more than the exporting countries, for two reasons: first, most of the original concession agreements, giving the companies exclusive crude-oil ownership rights, would have expired by the 1990s; and, second, most oil-exporting countries had limited investment opportunities at home and only risky investment opportunities abroad (given some risk to their foreign property rights), which meant that they might have preferred to conserve their appreciating oil reserves. Johany concludes by claiming (1982, p.139) that "the pre-October 1973 oil price reflected the true long-run costs of production [the replacement costs] as viewed by the Western oil companies, and the current [1982] price may reflect the actual long-run production costs as viewed by the oil-producing nations."
4. If the probability p is changing through time, then the expropriation process is not Poisson, and the result does not strictly hold. However, so long as there is a positive probability of expropriation in any period in the future, we assert that the equilibrium discount rate u will be greater than the market rate r.

How can the property-rights model of the world oil market be tested empirically? In a recent paper, Griffin (1985) postulates that "increases in the percentage of government-controlled production result in production cutbacks." He uses the percentage of government equity oil (Table 1) as a measure of the percentage of government control. Examining data for the period 1971 to 1981, he concludes that the null hypothesis that increases in the percentage of government ownership result in production cutbacks could not be rejected for 6 of the 11 countries. Griffin concludes that this "simple test" of the property-rights model provides "little support" for the hypothesis. Given that de facto nationalisation is as critical as government-controlled production, Griffin's exclusive reliance on the latter can mislead. Moreover, not every government need take a long-term perspective even if the most important countries determining the world price do. We thus place little reliance on Griffin's approach.

The model below shows that there is a simple relationship linking the implicit discount rate at any time, the price elasticity of demand (assuming an iso-elastic demand function), and the reserves/production ratio (or years remaining at current production). Since the discount rate cannot be observed directly, we are able to deduce its movements from these other variables on the basis of a set of assumptions, and we can observe whether or not the resulting path of the discount rate is plausible and consistent with a considerable amount of new evidence that we bring forth.

3. Competitive Market Model

We assume an iso-elastic demand for oil flow at any time t

$$R(t) = A(t)\ P(t)^{-\eta(t)}, \qquad \eta(t) > 0, \tag{1}$$

where $R(t)$ is the flow of oil produced at time t, $P(t)$ is the flow price at time t, and $\eta(t)$ is the price elasticity of demand for crude oil at time t; $A(t)$ is a shift parameter which models expansions or contractions of the demand schedule through time.

We assume that the marginal cost of extraction is zero, and hence for an exhaustible resource the Hotelling Rule states that the price of oil rises at the interest rate $r(t)$ at time t, ceteris paribus:

$$\dot{P}(t) \big|\ P(t) = r(t). \tag{2}$$

It is sufficient for this that the cost of extraction be zero and that oil is exhaustible. We make the assumption of *static expectations* in the three parameters, $\eta(t)$, $r(t)$, and $A(t)$; that is, for all time $\tau \geq t$,

$$\begin{aligned} A(\tau) = A(t) &= \bar{A}_t \\ \eta(\tau) = \eta(t) &= \bar{\eta}_t, \quad \text{and} \\ r(\tau) = r(t) &= \bar{r}_t. \end{aligned}$$

We further assume that no new discoveries are expected. These assumptions allow us to integrate equation (2) to obtain the expected price at any future time τ, given a constant discount rate $\bar{r}_t$:

$$P(\tau) = P(t)\ e^{\bar{r}_t(\tau - t)}, \qquad \tau \geq t. \tag{4}$$

$P(\tau)$ can be thought of as the *expected* price at any time τ later than t, given an expected constant discount rate $\bar{r}_t$ and no new discoveries.[5] From the transversality condition and equation (1), the optimum price path $\{P^*(t)\}$ can be solved from the condition that

$$S(t) = \int_t^\infty A(\tau)\ P^*(\tau)^{-\bar{\eta}_t}\ d\tau, \tag{5}$$

with constant price elasticity of demand, $\bar{\eta}_t$. Substituting equation (4) into equation (5) and assuming that $A(\tau) = \bar{A}_t$ is constant, we obtain

$$S(t) = \bar{A}_t\ P(t)^{-\bar{\eta}_t} \int_t^\infty e^{-\bar{r}_t \bar{\eta}_t (\tau - t)} d\tau. \tag{6}$$

If expectations are not static, then we can build these expectations into equations (2) and (5), but the result is still the same: an unexpected change in one of the four parameters at any time t will result in a compensating shift in the price level $P(t)$.

From equation (1), we can eliminate the price level $P(t)$ from equation (6), to obtain

$$S(t) = R(t) \int_t^\infty e^{-\bar{r}_t \bar{\eta}_t (\tau - t)} d\tau = \frac{R(t)}{\bar{r}_t \bar{\eta}_t}, \tag{7}$$

which can be rewritten as

$$R(t) = \bar{r}_t\ \bar{\eta}_t\ S(t). \tag{8}$$

The flow of oil is equal to the product of the instantaneous discount rate times the price elasticity of demand times the known stock of oil remaining (the reserves level).

If the demand for oil suddenly (unexpectedly) becomes more elastic, then the optimal flow of oil should rise, ceteris paribus. If there are new discoveries, increasing the known reserves unexpectedly, then the optimal flow of oil should rise. If the discount rate suddenly (unexpectedly) falls, then the optimal flow of oil should fall, ceteris paribus. It is this event we seek evidence of. The relationship (8) does not include price $P(t)$ explicitly. But, from equation (1), a shift in $R(t)$ or $A(t)$ or $\eta(t)$ will occur together with a shift in $P(t)$, and from equation (8) $R(t)$ will shift if $\bar{r}_t$, $\bar{\eta}_t$, or $S(t)$ change.

We can formalize this discussion, in the form of a theorem:

Theorem 2: The discount rate $\bar{r}_t$ equals the reciprocal of the product of the price elasticity of demand and the reserves/production ratio, $\gamma(t)$:

$$\bar{r}_t = \frac{1}{\bar{\eta}_t}\ \frac{R(t)}{S(t)} = \frac{1}{\bar{\eta}_t \gamma(t)}, \tag{9}$$

Corollary: If the expected level of demand at any price is not constant, but growing at a constant proportional rate $\bar{g}_t$, then the four parameters are related by the equation

---

5. It is unlikely that, over any stretch of years, there will be no new discoveries or no shifts in the discount rate, but so long as these are unanticipated then equation (4) describes the expected price trajectory. Alternatively, in a rational-expectations framework expected future discoveries would already be incorporated within the anticipated stock of oil. In Section 5.3 below we discuss how "rational expectations" forecasts could be made.

$$\bar{r}_t = \frac{\frac{1}{\gamma(t)} + \bar{g}_t}{\bar{\eta}_t}. \tag{10}$$

Proof: A constant growth in demand at any price is modeled by

$$\dot{A}(t)/A(t) = \bar{g}(t),$$

which, with constant expected growth rate $\bar{g}_t$, can be integrated to obtain

$$A(\tau) = A(t)e^{\bar{g}_t(\tau - t)}, \qquad \tau \geq t,$$

from which the demand at any time is given by

$$R(\tau) = A(t)P(t)^{-\bar{\eta}_t}e^{(\bar{g}_t - \bar{r}_t\bar{\eta}_t)(\tau - t)}.$$

Whence,

$$S(t) = \frac{R(t)}{\bar{r}_t\bar{\eta}_t - \bar{g}_t},$$

or

$$\bar{r}_t = \frac{\frac{1}{\gamma(t)} + \bar{g}_t}{\bar{\eta}_t}.$$

for a growth rate $\bar{g}_t \leq \bar{r}_t\bar{\eta}_t$. □

4. From a Global to a Regional Approach

The very simple relationship, equation (9), asserts that, along an equilibrium Hotelling growth path, with no "surprises" and with a given exogenous rate of interest or discount $\bar{r}_t$, reductions in $\bar{r}_t$ result in reductions in the current extraction rate $R(t)$ relative to the stock $S(t)$, which results in rises in the price $P(t)$, ceteris paribus. This means that those who—like Griffin (1985)—reject the property rights hypothesis in favor of the cartel explanation for the 1973/74 oil price rise must maintain either that the fall in $\bar{r}_t$ did not generate the oil price rise or that all of the maintained hypotheses giving rise to the relationship between price and the discount rate are incorrect.

4.1 Relaxing the Assumptions of Competition and Exhaustibility

In the simple case of a constant elasticity of demand facing a cartel, relaxation of the assumption of competition underlying (9) will not alter the relationship. If the elasticity of demand facing the cartel tends to rise over time because the overall demand is linear or because substitutes or a competitive fringe become more competitive as reserves dwindle, then the cartel or monopoly will be more conservation-minded (Stiglitz, 1976).[6] Moreover, if there are significant extraction costs, the cartel or monopoly will be more conservative in its extraction policy (Dasgupta and Heal, 1979, pp.333–334). Under these circumstances the losses to consumers in the early years of the cartel's existence will be partly compensated for by gains which accrue to later generations of consumers, who will benefit from the greater surviving stocks of the resource.

---

6. The possibility of the monopoly or cartel being able to dispose of unwanted reserves, or being able to pre-commit itself never to use such reserves, is not allowed for in this result.

Apart from relaxing the assumption of competition within the exhaustible resource framework, we can also relax the assumptions relating to exhaustibility. The reason for doing so is that only for a non-exhaustible good does monopoly or cartelization have the conventional adverse impact on consumers of the static, produced good which is non-exhaustible.[7] Conservation-minded policies cease to have any redeeming virtues in this framework.

In the limit as the stock of the exhaustible resource gets larger relative to extraction costs, its properties approach those of conventional non-exhaustible goods. With a constant extraction cost, in the limit the scarcity rent of the in situ resource is zero and the extracted price of the resource is equal to its marginal extraction cost. Relatively poor grades of coal in countries such as Australia which are well endowed with coal may be an example of an abundant but exhaustible resource for which the scarcity rents are low.

Even for a relatively abundant resource, the strictures of the Hotelling model and equation (9) still apply, with the net-of-extraction-cost price, $Q(t)$, still rising at the market discount rate. The price of the extracted resource will rise at a much slower rate because the scarcity rent is initially very low. Only in time, as the stock of the resource dwindles, will the extracted resource price rise at a rate which reflects the now much higher scarcity-rent element.

This has an interesting implication for the owners of a relatively abundant exhaustible resource. Suppose that all reserves are of the same grade and that extraction costs are uniform (and unaffected by depletion) across all deposits or fields. The rising value of the scarcity-rent element of the price will exactly offset the force of the discount rate's encouraging rapid extraction, leaving the resource owner indifferent between early and late extraction. Thus the finding by Miller and Upton (1985)—that the share-market values of oil and gas companies in the same situation is the same regardless of whether one company has postponed extraction or not—is quite consistent with an extracted oil price which is growing at a much slower rate than the interest or discount rate.[8]

Dasgupta and Heal (1979, p. 171) ask the question: "how large is large?" That is, how large do stocks have to be for extraction costs to dominate? They conclude that initial stocks are "large" in the relevant sense if the scarcity rent is less than about 1% of the extraction cost. This situation does not seem to have been applicable to the Middle Eastern fields prior to the 1973/4 price increase, when the extraction cost was as little as US$0.10/bbl from a low-cost field, with a price per barrel in the range of $1.00 to $2.00, so that scarcity rents were well in excess of extraction costs even before the oil price hike to $10.00/bbl. Given these low extraction costs, both the scarcity rent and

---

7. The reason for the difference is that the monopoly producer of a non-exhaustible good produces less than that of an equivalent competitor. For an exhaustible good the same total quantity is supplied over the life of the good, unless reserves can be destroyed by the monopoly and thus never used.

8. If, as we suggest, there was disequilibrium in the world oil market between 1956 (Suez) and 1974 (post-Embargo), then a test of Miller and Upton's Hotelling Valuation Principal during that period would prove negative.

extracted price could be expected to rise at approximately the market discount rate. It is thus difficult to appeal to the abundance of oil even before the oil price hike as a means of escaping the implication of equation (9)

The assumptions underlying equation (9) could also be relaxed by supposing that the market discount rate $\bar{r}_t$ is exceedingly high for oil companies. This might be because (it might be argued) few oil producers have complete security of tenure over their leases and many are under considerable pressure to pump oil as fast as is technically feasible from governments concerned only with the next election. In Australia, for example, insecurity of tenure was enshrined in an allocation system for leases based on the magnitude of the promised drilling program—so-called Work-Program Bidding. Moreover, the Crown would normally require a portion of the lease area to be relinquished for reallocation each year or so. A company which found commercial quantities of oil would be likely to lose its rights to the oil unless it pumped at some technically maximum rate. Indeed, the Australian Government came to depend heavily on the royalties and tax revenue produced by the Esso-BHP wells in Bass Strait. No Australian government would have countenanced a policy of minimal extraction from these wells.

One piece of evidence which does support the hypothesis of a general lack of clearly defined long-term property rights is the development and exploitation of many high-marginal-cost fields, such as the North Sea, and the rising cost of discovery and extraction in the major oil exploration areas, as indicated by Ivanhoe's Discovery Effort Index (Section 5.2 and Figure 2 below). The political pressure in the West after 1973 to relieve the "energy crisis" has been immense. Moreover, the considerable rise in oil production over the period of falling or depressed oil prices, 1956–1973, is also indicative of political or other pressure on oil companies to extract even when prospective capital gains from capping are greater. (Note, however, the US experience described in Section 5.1 below.) These gains from capping high-cost fields exceeds the return from pumping so long as low-cost fields are being exploited.

The discovery of new high-cost fields may be consistent with the Hotelling model with property rights, but extraction of high-cost oil is not on the face of it consistent with the simple Hotelling story. To see this, imagine two fields, a low-cost Middle East field and a high-cost North Sea field. Suppose the extraction costs are effectively zero in the first field but are high in the second. If property rights are applicable, the rent component of the price of oil net of extraction cost will rise at the market rate of discount $\bar{r}_t$. But this net price is also the price of oil from the Middle East, where extraction costs are virtually zero. The world price will be determined by the price for Middle East oil, and hence the extracted price of oil will also increase at the market interest rate. An owner of a high-cost North Sea field will anticipate that the price of extracted oil will rise at the rate $\bar{r}_t$. Since this owner with high extraction costs is earning only a small rent component, this rent component on in situ oil will grow at a much faster rate than the rate $\bar{r}_t$, which is common to all producers. Consequently, in a perfect capital market the owner of the high-cost reserves will prefer anticipating the capital gains obtained from leaving the reserves in the ground to obtaining the lower rate $\bar{r}_t$ from reinvesting the earnings from extracted oil at the market interest/discount rate.

One would expect no extraction from the high-cost field until the low-cost Middle East field is exhausted, at which point the rent component of the price of oil will continue to rise at the rate $\bar{r}_t$ but, since only high-cost North Sea oil remains, the price of extracted oil will now rise much more slowly. Since there are no longer any relative gains from retaining high-cost oil in the ground, high-cost fields can now be economically exploited.

The question arises: how susceptible were the crucial Middle East countries toa property-rights change conducive to conservation strategies? Given the enormous build-up of "petro-dollars" from the OPEC countries post-1974, it is clear that for a number of years at least the domestic infra-structure did not exist to enable the revenue to be spent domestically. Consequently, there could be no pressure to extract more oil to fund current projects. This enabled Sheik Yamani and the other OPEC oil ministers to pursue their long-term regional interests by adopting a conservationist strategy. This long-term perspective has weakened in recent years, perhaps as domestic expenditure programs have expanded to the point where existing oil revenues are inadequate. Perversely, the attempt to meet minimum revenue requirements by weakening the long-term property rights approach has contributed to the excess supply situation for oil and to the dramatic price fall which occurred in 1986 (see Ball and Marks, 1986).

It therefore seems likely, for the important OPEC producers at least, that a long-term perspective in which property rights could flourish for some time is both feasible and likely. In Saudi Arabia the presence of an entrenched ruling royal family may have added to the ability to pursue a long-term strategy. A royal family is not under electoral pressures every two or three years as are most Western governments. Moreover, the royal rulers know that their descendants or close relatives are likely to benefit from conservation policies adopted now. Nonetheless, a king is subject to the threat of a coup from other members of his family or from outside forces. These threats may have increased in recent years now that expenditure exceeds revenues. Members of a conservative government may not feel similar kinship towards members of a future labor government, and vice versa.

From this discussion it is clearly very hard to relax the assumptions of the Hotelling model underlying our approach and find a set of circumstances in which the cartel hypothesis plays a rôle and the usual economic strictures against the cartelization of an industry are applicable also.[9] If oil is not exhaustible in the relevant economic sense, then the high-rent component of Middle East oil even prior to 1974 is very hard to explain. If property rights are non-existent in oil, then cartelization may be seen as moving the industry in the desirable direction of greater conservation.

Returning now to our basic relationship, equation (9) above, we need to interpret the significance of the reserves/production ratio, γ.

---

9. Within the context of oil as an exhaustible resource, Pindyck (1978) has argued that the competitive supply response facing a cartel is sufficient—in combination with production lags—to generate gains to a cartel. He does not compute the social costs of a cartel.

4.2 The Middle East and the Rest of the Non-Communist World

Since this ratio relates to the entire anticipated world supply and demand for oil rather than to any individual reserves, country, or region, ratios for particular regions (such as the Middle East) have no particular significance in terms of our formulation, (9) above. Let us divide the world into two regions: OPEC countries—essentially the Middle East—and the rest of the world. Suppose for the period roughly from 1956 (the time of the Suez Crisis) until 1974 that the threat of nationalization meant that property rights for the seven major oil companies in the Middle East were highly insecure, so that the discount rate for such producers was very high. Suppose that while there was also insecurity of tenure in the rest of the world there was sufficient stability for the relevant discount rate to be close or equal to the market yield on assets.

The high and rapidly growing production in the Middle East due to the fear of nationalization would have meant that the rest of the world anticipated a constant or even falling price of oil actually extracted from fields until such time as the prospective nationalization actually occurred.[10] Once this happened, the Middle East would slow down the rate of increase in production—or production itself—until the rent component of the price of oil began to rise at the market rate of discount. This would require a substantial rise in the price of oil, which would occur as a large anticipated jump at the (previously unknown) date of nationalization.

The prospective capital gain to the rest of the world from holding in situ oil reserves so as to take advantage of the price rise following nationalization would exceed the revenue which could be obtained from selling the extracted oil on the depressed market, but, since there are generally technical limits to the extent to which the rate of extraction from existing wells can be reduced, one would not expect the complete cessation of production over this period. Hence, we would expect the share of Middle East oil to rise over the period 1956–74 and then to contract once property rights were established in the Middle East. On the basis of this hypothesis, not only would the rest of the world's share fall until 1974, but its output might fall in absolute terms as well.

The alternative hypothesis is that property rights in the rest of the world have from the mid-1950s at least been relatively poorly defined and that the situation has progressively worsened as governments have put increasing pressure on oil companies to relieve the so-called "energy crisis" by even faster extraction. On the basis of this hypothesis, production in the rest of the world would continue to rise, but reserves/production ratios might perhaps remain relatively stable. Support for this hypothesis also stems from the difficulty of explaining why extraction takes place *at all* from relatively high-cost fields in the rest of the world, given the capital gains which accrue to owners of high-cost fields while the low-cost Middle East fields are being depleted.

---

10. The Middle East fields are so large relative to the rest of the world that exhaustion of these fields was most unlikely to occur prior to nationalization. Moreover, the flood of Middle East oil onto world markets occurred on such a vast scale that it could not be countered by a contraction in the rest of the world's production.

Given the evidence from Table A1 in the Appendix that output rose in the rest of the world between 1956 and 1974, we thus prefer the hypothesis—over the period 1956–1974 at least—that property rights in oil tended to favor rapid extraction worldwide. Increased Arab nationalism at the time of the Yom Kippur war and the short-lived oil embargo in 1974 were the changes which signaled a new set of longer-term owners of oil in the Middle East. Since Middle East oil reserves make up most of the potential supply of the non-communist world, we should expect that a Hotelling extraction and price path would be obtained, with the anticipated price increase for oil close to the market interest rate.

5. Empirical Evidence

5.1 Reserves/Production Ratios

Figure 1 plots the reserves/production ratios for the three regions of the USA, the Middle East,[11] and the Rest of the Non-Communist World (RNCW), and the Non-Communist World (NCW) as a whole, from 1951 to 1985, based on data published in the *BP Statistical Review*.[12] The reserves are the "published proved" reserves at end-December, generally taken to be "the volume of oil remaining in the ground which geological and engineering information indicate with reasonable certainty to be recoverable from known reservoirs under existing economic and operating conditions," and are the figures published at that time. As such, they provide a reasonably consistent time series of known reserves at each date.[13]

Two observations can be made about Figure 1: first, the three regions do not have the same mean reserves/production ratios over the period: the USA ratio is lower than the RNCW ratio, which is less than the Middle East ratio. Second, the ratio for the Middle East producers exhibits behavior which is not reflected in the other ratios. From 1951 to 1957 the Middle East reserves/production ratio rose monotonically to a maximum of 130 years and then fell until 1973 with but one rise (in 1968). From 1973 to 1979 the ratio fluctuated around 50 years, but thereafter rose monotonically to a value of 100 years in 1985. The USA ratio, meanwhile, rose from under 7 years in 1951 to over 11 years in 1971, after which it fell slightly. The rest of the non-communist world (RNCW) on the other hand, fluctuated between 15 and 30 years, with a high point of 32 years in 1972.

As much as anything, the different regional reserves/production ratios clearly indicate the regions with abundant oil (Middle East) and scare oil (USA). Yet the

---

11. Iran, Iraq, Kuwait, Neutral Zone, Qatar, Saudi Arabia, and others.
12. See Table A1 for reserves and production data, and the reserves-to-production ratios plotted in Figure 1, which does not include data from the USSR, Eastern Europe, or China.
13. The ratios for 1972 and 1974 seem anomalous. The RNCW reserves figures are influenced by an anomaly in the African figures: from 58.9 bbl $\times 10^9$ at end 1971 to 106.4 at 1972 to 67.3 at 1973 and 68.3 at 1974. The NCW reserves figures at end 1973, 1974, and 1975 were 531.7, 609.0, and 652.7 bbl $\times 10^9$, while production during 1974 and 1975 was only 17.4 and 16.0 bbl $\times 10^9$ respectively. Did the oil price rises of 1973/74 overwhelm the caution of producing governments when estimating their reserves, especially now that they had gained control over their oil?

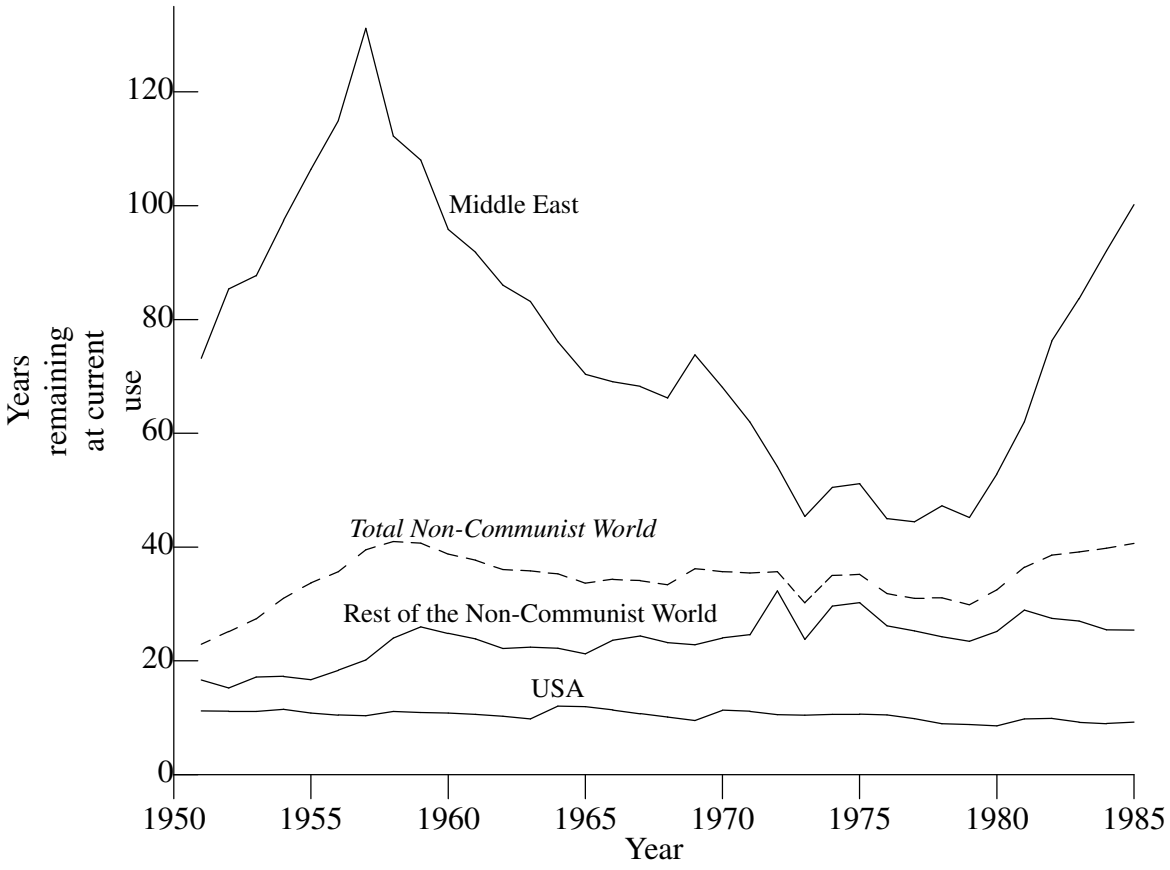

Figure 1: RESERVES/PRODUCTION RATIO
Source: *BP Statistical Review*

extraordinarily high rate of extraction in the USA relative to reserves is the opposite of what one would expect on the basis of the property-rights analysis applied to the USA. If the US owners were entirely confident that they could enjoy rents from future extraction without the threat of expropriation, then their high-cost fields would be capped rather than exploited. Since much US oil from Alaska and off-shore is on land leased from governments, the terms of these leases may encourage rapid extraction. The common field problem (Wiggins and Libecap, 1985) may also exacerbate excessive production levels in the US. We thus interpret Figure 1 as supporting the hypothesis of weak property rights in the United States.

In his revisionist explanation for the 1973/74 oil price rise—which does not rely on an OPEC cartel—Meade (1986, p.216) draws attention to the peaking of US oil production in 1970 and the subsequent decline until 1976 at 2.75% per annum. This decline is consistent with the property-rights explanation. Together with increased demand due to the low prices, US oil imports increased rapidly from 1,324 bbl/day

(11.8% of total US crude oil consumption) in 1970 to 3,244 bbl/day (25.7%) in 1973 to 6,615 bbl/day (43.3%) in 1977.

5.2 An Effort of Discovery Index

The model of Section 3 was for a unitary world. What can that model say about three regions with different paths for their reserves/production ratios? If all regions sell on the same market—as they tend to do—then the growth in demand and the price elasticity of demand are the same across regions. Given a single world market for oil, only the series for the Non-Communist World as a whole matters in terms of our theory encapsulated in equations (9) or (10) above.

What other factors are different between the three regions? Figure 2 (from Ivanhoe, 1984) plots the "Discovery Effort Index" for the USA (excluding Alaska) and the rest of the world (including the Middle East) over the period. The Discovery Effort Index is the number of feet of exploratory drilling required per barrel of recoverable oil discovered: it is the reciprocal of Ivanhoe's Discovery Index. We note two things from the Index: first, the USA has a far higher Discovery Effort Index than does the rest of the world; second, the Discovery Effort Index for all regions is rising through time, implying a rising marginal cost of replacement (MCR) of oil in the world. More precisely, the Index rises rapidly until about the time of the Suez crisis, remains roughly constant or falls slightly from then until the OPEC Embargo in 1973/4, and then continues to rise at much the same rate as it had prior to the mid-1950s.[14] Ivanhoe notes that this is happening at a constant rate of 7% per annum, his "flush-Discovery-Index-decline" rate, which appears on Figure 2 as a flush-Discovery-Effort-Index growth rate. As indicated in Section 5.3 below, this 7% rate is of considerable significance.

The "extensive margin" of exploratory drilling will be the level of drilling at which the marginal cost of drilling equals the scarcity (quasi-) rent.[15] Comparing the USA and the Middle East, and given the lower average cost of discovery in the Middle East, we should not be surprised that, when both regions face the same oil price, the level of proved reserves is higher in the lower-cost Middle East; this explains the higher Middle East reserves/production ratio. Governmental pressure to extract even high-cost oil accounts for drilling and extraction in the rest of the world well before Middle East reserves show any sign of exhaustion (Ball and Marks, 1986).

---

14. The middle period shown in Figure 2 is identified by Ivanhoe as corresponding to the introduction of new, digital seismic technology in exploration.
15. The cost of drilling per barrel found must equal the scarcity (quasi-) rent on the extensive-margin field so that the per-barrel cost of drilling rises at the same rate as net price on the marginal field. Since the price of oil will rise at the same rate as the rent component on a low-cost field, drilling costs will tend to rise at a faster proportional rate than the price of oil itself. We note that the three periods identified by Ivanhoe on his graph—prior to the mid-1950s, the mid-1950s to the Oil Embargo, and from the Oil Embargo onwards—correspond to the periods we identify as strong property rights, non-existent property rights, and the return to strong property rights.

5.3 The Reserves/Production Ratio in the Middle East

The property-rights theory tells us that as the perceived risk of expropriation rises, the discount rate rises; after expropriation occurs, the discount rate will fall to the world interest rate. Our model suggests that a higher discount rate corresponds to a lower reserves/production ratio. These observations help us to explain the four regimes of the Middle East reserves/production ratio.

The first regime (1951–1957) can be explained by a combination of a very low Discovery Effort Index in the Middle East being reflected in rapidly growing reserves (from 51.30 to 169.45 bbl $\times 10^9$) with lagging production in the period. However, the dramatic turnaround in the reserves-to-production ratio in 1957/58 suggests that the possibility of effective expropriation became evident in that period. (Several years earlier the unsuccessful expropriation by the Iranians of the assets of the Anglo-Iranian Company—British Petroleum—had been stymied by the oil majors, who stepped up production elsewhere and refused to buy crude from the nationalized Iranian fields.) The Suez debacle may have altered the perceptions of the Middle East producers, over two years before the formation of OPEC in 1960.

The fall in the reserves/production ratio was virtually uninterrupted from 1957 to 1972, reflecting increasing fears of expropriation on the part of the oil-producing companies in the Middle East, which in turn resulted in rising discount rates and increased production. During this period, with a positive likelihood of expropriation and the firm's discount rates higher than the world interest rate, the firms would have attempted to expand production as fast as technically possible from their Middle East fields. In 1958, Middle East production was 26% of the NCW's, but by 1973 it had risen to 43%. Meanwhile, the real world oil price had fallen to its lowest post-war level. With a falling price of oil, theory tells us that oil producers with secure property rights will reduce production to the minimum necessary, waiting until the price of the exhaustible resource inevitably rises.

Figure 3 plots the numbers of operating rigs over the period 1951–1987, and provides corroborative evidence of the regimes discussed above.[16] In the early 1950s, the numbers of rigs grew rapidly outside the USA, until 1957 when a slackening of growth occurred. From 1960, the number of rigs remained roughly constant or falling until 1974, which is consistent with weaker property rights. After the first oil price rise of 1973/74, the four-fold increase in the numbers of rigs in the Middle East—a much larger increase than the rest of the world—is quite consistent with a transfer of property rights to the producing states. Severe price controls on domestic oil in the USA which artificially boosted world prices may also have slowed the growth in US oil exploration. The ten years after 1975 are characterised by constant numbers in the Middle East, but at first growing numbers in the USA and elsewhere in the Non-Communist World. (The second price rise of 1979/80 apparently stimulated drilling efforts in the USA, but why not elsewhere? The answer is that it was more the deregulation of the US market—and hence higher well-head prices domestically—which led to the surge of drilling, and less

16. The figures aggregate exploratory and developmental drilling, and so overestimate the exploratory (wild-cat) effort.

the increase in the world price.) Finally, the 1986 oil price slump has meant falls in rig numbers everywhere, although proportionately most in the USA and least in the Middle East.

5.4 The Implicit Discount Rate

In Figure 4 we have plotted the implicit discount rate for the Non-Communist World, derived using equation (10). For $S(t)$, the total stock of oil remaining, we have used dated estimates of the ultimate size of the world's oil resource base.[17] For $\bar{g}_t$, the expected growth in underlying demand, we have used the four-year average annual increase in oil production from Table A1: until 1974 there was little change in the real price of oil, and a low price elasticity of demand means that most of the change in production came from shifts in the demand schedule anyway. The price elasticity of demand was assumed to be 0.25, a low figure, although we allow it to rise in a second calculation, to mimic more realistically the behavior of a linear demand function.

Figure 4 plots the implicit annual discount rate using equation (10) and the data of Table A2, shown by the solid line. The calculated series demonstrates the fall around 1974 that the property-rights theory predicts. The production figure, and hence the calculated discount rate, includes all producers, not just those who anticipate expropriation. Not a great deal of significance can be attached to the (apparently high) level of the rate before 1973 because of the lack of property rights giving rise to a disequilibrium solution driven by technical limits to production.[18]

After the transfer of control of 1973/74, the calculated discount rate fluctuates around 10% per annum, until a jump in 1979, perhaps reflecting the uncertainty associated with the downfall of the Shah. (A rise in 1956 likewise might reflect the short-term effects of the Suez crisis.) Thereafter, the rate, indicated by the solid line, fell to almost −15% per annum in 1983, driven by the falls in production of the early 1980s.

In our opinion the price increase and continued high prices after the Iranian crisis reflect in part at least the boost to world oil consumption from the short-sighted import-subsidy policies adopted in the United States and other countries, such as Australia. The freezing of the price of domestic oil and the setting of the price of oil in these countries on a weighted-average basis maintained world consumption levels and slowed adjustment. The subsequent introduction of world parity pricing for oil removed this artificial stimulus to demand, and has contributed to the recent glut in the world oil market.

Using a dotted line, Figure 4 also plots a second series of discount rates,

---

17. From 20 estimates made between 1941 and 1972 of the ultimate size of the world's oil resource base (Kirkby and Adams, 1974), we obtained: $S(t) = 500 + 60.34(t - 1942)$, where $S(t)$ is the estimate in year t of the Non-Communist World's ultimate oil resources (in bbl$\times 10^9$). We noted a strong trend for later estimates to be larger, growing arithmetically.

18. So long as the Middle East countries which dominate world stocks of oil face an effective discount rate greater than the market rate, r, then the rate we calculate, $\bar{r}_t$, will exceed the market rate and reflect the technical limits on oil production in the Middle East rather than the anticipated Hotelling growth rate in the price of oil.

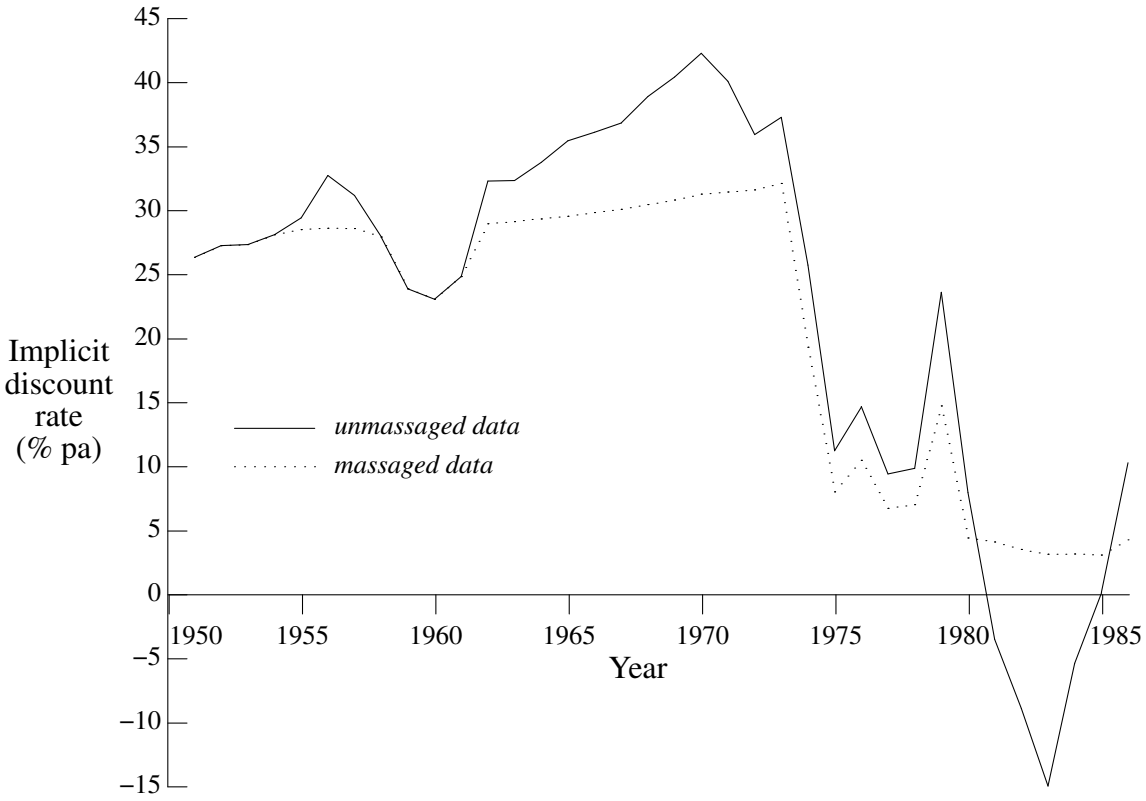

Figure 4: IMPLICIT DISCOUNT RATE

calculated from data in Table A2, which differ from the previous one in two respects. To better reflect long-run expectations of growth in the demand schedule, the four-year average growth in oil production has been constrained to a ceiling of 6% per annum and a floor of 0.5% per annum. In addition, after 1973 the price elasticity of demand rises from 0.25 to 0.35 in 1975, and then 0.6 in 1983, which reflects both the rising price elasticity associated with a linear demand for oil, and the greater awareness of oil-saving possibilities stimulated by the two oil-price shocks of the 1970s.

Comparison of the two series in Figure 4 reveals that the constraints on $\bar{g}_t$ result in bounds on calculated $\bar{r}_t$, and the higher values of $\bar{\eta}_t$. This revised series for $\bar{r}_t$ in the post-1974 era indicates an average annual discount rate in the range of 5 to 10% real. These implicit discount rates thus span the 7% average annual rate of increase in our flush-Discovery-Effort Index, which is closely related to the oil explorers' estimate of the anticipated rate of growth in oil prices. Thus the overall behavior of the "massaged" implicit discount rate in particular seems reasonably plausible to us.

6. Conclusions

From a model of discount rates with risk of expropriation of assets, we have derived a simple expression linking the implicit discount rate, the price elasticity of demand, the stocks-to-flow (reserves-to-production) ratio, and the growth of the demand schedule.

In contrast to other revisionists (Roumasset, Isaak, and Fesharaki, 1983), we have not resorted to a rising cost function to drive our model. Moreover, to some extent, the fall in world real interest rates at the time of the oil price rises was an endogenous rather than an exogenous factor. The massive accumulation of petro-dollars depressed world interest rates. We argue, as do Roumasset et al., that it is not necessary to assume effective market power on the part of the OPEC producers at least to obtain the pattern of prices (and implicit discount rates) seen from the early 1950s to the mid-1970s. From market data we have calculated implicit discount rates that behave as the property-rights theory would predict. Moreover, the "massaged" series of implicit discount rates seems reasonably plausible, even though our model may not properly capture the implicit discount rate prior to 1973/4—apart from its excessiveness—because of possible disequilibrium then.

Perhaps more importantly, we have attempted to explain why high-cost fields outside the Middle East continued to be developed from at least the mid-1950s onwards. The high rents accruing to Middle East oil and its exhaustibility would indicate that high-cost fields outside the Middle East, such as the North Sea, should not be developed, even if discovered, prior to the depletion of the low-cost Middle East fields. But the observed premature exploitation means that owners of fields in Europe and the USA are acting as if their discount rate were exceedingly high—sufficient to cover the large capital gains they must earn on the small rent component of their reserves as the low-cost Middle East fields face exhaustion. This high discount rate is explicable once the dependence of many governments on the tax revenues from oil is recognized. From the Bass Strait fields alone the Australian Government has annually received up to 8.6% of its taxation revenues, which exceeds total company-tax collections by a considerable margin. The British Government and a number of European governments are similarly dependent on North Sea oil. The very-short-run nature of governmental policies is driven by the frequency of elections. Oil companies producing in Western democracies are generally forced to extract at close to the technical maximum rate.

The generally excessively rapid depletion of non-Middle East reserves implies that, even if OPEC were in part able to act as an effective cartel, the Organisation deserves credit for introducing long-overdue conservation policies that benefit generations of consumers yet unborn. The implausible cartel explanation is in fact an unnecessary embellishment to the far simpler and more satisfying explanantion—changing property rights—in which the producing nations obtain de facto control of oil production in the post-Oil Embargo era. Occam's razor has been used to slash away the notion of an effective, disciplined cartel which nonetheless lacked the means to enforce any decrees it made. OPEC provided a convenient scapegoat for the West. Of necessity, relatively long-term conservationist strategies had to be followed, since the producing nations could not on the whole absorb petro-dollars at the rate they were being generated.

It is our contention that unless or until the Middle East oil producers are overwhelmed by short-term revenue implications, as their Western counterparts have been, the exhaustibility of oil will continue to dictate a long-run anticipated real price increase of between 5 and 10% per annum, which corresponds to a general range of real

market/discount rates. A point estimate of the anticipated average rate of real price increase for in situ oil is given by our flush-Discovery-Effort-Index growth rate of 7% per annum, the rate at which drilling depth per barrel of discovered oil is increasing in marginal fields worldwide. Since this will tend to exceed the anticipated price increase for oil itself, we favour the lower estimate of about 5% per annum.

The observed—ex post rather than ex ante—price of oil can be expected to fluctuate around this long-run upward trend owing to crises and short-run supply and demand factors; the price of a non-exhaustible product may exhibit similar volatility around a stationary long-run equilibrium price. The oil price slump of 1986, following the exceedingly high levels of the post Iranian crisis period, tends to lend support to the view that the prices experienced over this period were really something of an aberration engendered by a crisis mentality and a short-run demand elasticity which remains quite low. The long-run upward pressure on oil prices from exhaustibility means that oil companies must educate both themselves and governments about the virtues of less-than-maximum extraction rates from reserves.

Year	U S A			Middle East			Rest of the NCW			Non-Communist World		
	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R
	bn bbl	m bbl/d	years	bn bbl	m bbl/d	years	bn bbl	m bbl/d	years	bn bbl	m bbl/d	years
1951	27.47	6.72	11.20	51.30	1.92	73.20	16.75	2.76	16.63	95.52	11.40	22.96
1952	27.96	6.87	11.15	64.79	2.08	85.34	16.30	2.93	15.24	109.05	11.88	25.15
1953	28.94	7.12	11.14	77.78	2.43	87.69	18.80	3.00	17.17	125.52	12.55	27.40
1954	29.56	7.03	11.52	97.39	2.74	97.38	20.52	3.25	17.29	147.47	13.02	31.03
1955	30.01	7.58	10.85	126.21	3.25	106.39	22.52	3.69	16.72	178.74	14.52	33.73
1956	30.43	7.95	10.49	144.35	3.44	114.97	28.17	4.20	18.38	202.96	15.59	35.67
1957	30.30	7.98	10.40	169.45	3.54	131.14	34.69	4.71	20.18	234.44	16.23	39.57
1958	30.53	7.52	11.12	173.88	4.24	112.22	40.26	4.59	24.00	244.67	16.36	40.97
1959	31.72	7.93	10.95	181.37	4.60	108.02	47.46	5.00	26.00	260.54	17.53	40.71
1960	31.61	7.97	10.87	183.09	5.24	95.82	49.53	5.47	24.83	264.23	18.67	38.78
1961	31.76	8.18	10.64	188.13	5.61	91.79	51.84	5.95	23.85	271.73	19.75	37.70
1962	31.39	8.35	10.30	193.88	6.18	86.02	54.97	6.78	22.19	280.23	21.31	36.03
1963	30.97	8.64	9.82	207.02	6.82	83.16	60.21	7.35	22.44	298.20	22.81	35.82
1964	38.70	8.77	12.09	211.50	7.61	76.09	66.30	8.17	22.23	316.50	24.56	35.31
1965	39.40	9.02	11.97	214.90	8.36	70.38	69.50	8.96	21.25	323.80	26.34	33.68
1966	39.80	9.58	11.38	234.60	9.31	69.07	83.30	9.65	23.65	357.70	28.53	34.34
1967	40.00	10.22	10.72	248.50	9.98	68.25	93.30	10.48	24.39	381.80	30.67	34.10
1968	39.30	10.60	10.16	270.10	11.18	66.19	99.70	11.77	23.22	409.10	33.54	33.41
1969	37.80	10.83	9.56	332.80	12.36	73.77	110.00	13.19	22.86	480.60	36.38	36.20
1970	46.70	11.30	11.33	343.90	13.84	68.08	130.10	14.82	24.05	520.70	39.96	35.70
1971	45.40	11.16	11.15	366.80	16.20	62.01	131.10	14.61	24.58	543.30	41.98	35.46
1972	43.10	11.19	10.56	355.30	17.97	54.17	176.30	14.95	32.31	574.70	44.10	35.70
1973	41.80	10.95	10.46	349.70	21.11	45.39	140.20	16.14	23.81	531.70	48.19	30.23
1974	40.60	10.48	10.61	403.40	21.89	50.50	165.00	15.25	29.64	609.00	47.62	35.04
1975	38.90	10.01	10.65	368.30	19.72	51.18	155.50	14.06	30.29	562.70	43.79	35.21
1976	37.30	9.73	10.50	367.30	22.35	45.02	146.30	15.32	26.16	550.90	47.40	31.84
1977	35.50	9.86	9.86	365.80	22.55	44.45	154.40	16.73	25.29	555.70	49.13	30.99
1978	33.70	10.27	8.99	369.60	21.42	47.26	151.70	17.15	24.23	555.00	48.85	31.13
1979	32.70	10.14	8.84	361.80	21.91	45.24	164.70	19.24	23.46	559.20	51.28	29.88
1980	31.90	10.17	8.59	362.00	18.75	52.88	174.70	19.01	25.18	568.60	47.94	32.50
1981	36.50	10.18	9.82	362.60	16.01	62.03	193.50	18.33	28.92	592.60	44.53	36.46
1982	36.90	10.20	9.91	369.00	13.27	76.16	186.60	18.60	27.49	592.50	42.08	38.58
1983	34.50	10.24	9.23	369.70	12.11	83.64	189.20	19.18	27.02	593.40	41.54	39.14
1984	34.50	10.51	9.00	398.40	11.85	92.07	190.50	20.51	25.45	623.40	42.87	39.84
1985	35.60	10.54	9.25	397.50	10.87	100.19	193.10	20.81	25.43	626.20	42.22	40.64

TABLE A1. Reserves (S), Production (R), and Reserves/Production Ratio (S/R)

Source: *BP Statistical Review of World Energy* and *Oil & Gas Journal*

Notes:

1. Reserves (S) are "published proved" at end-December, from that year's *Review*. Proved reserves are "generally taken to be the amounts of oil discovered in well delineated reservoirs that can be recovered commercially by presently available techniques at present costs and present prices."
2. For the USA the data include oil which it is estimated can be recovered from proved natural-gas reserves.
3. The Middle East (ME): Abu Dhabi, Iran, Iraq, Kuwait, Saudi Arabia, and others.
4. The Non-Communist World (NCW) excludes China, the USSR, and other centrally planned economies.

Year	Production	Estimated ultimate reserves	Growth rate 4-year	Price elasticity of demand	Implicit discount rate	Growth rate 4-year	Price elasticity of demand	Implicit discount rate
	m bbl/d	bn bbl	pc pa		pc pa	pc pa		pc pa
			Unmassaged			*Massaged*		
1951	11.40	1,043	5.50	0.25	26.372	5.50	0.25	26.372
1952	11.88	1,103	5.74	0.25	27.268	5.74	0.25	27.268
1953	12.55	1,164	5.76	0.25	27.352	5.76	0.25	27.352
1954	13.02	1,224	5.97	0.25	28.134	5.97	0.25	28.134
1955	14.52	1,284	6.23	0.25	29.443	6.	0.25	28.523
1956	15.59	1,345	7.03	0.25	32.756	6.	0.25	28.636
1957	16.23	1,405	6.64	0.25	31.180	6.	0.25	28.620
1958	16.36	1,466	5.87	0.25	27.943	5.87	0.25	27.943
1959	17.535	1,526	4.83	0.25	23.916	4.83	0.25	23.916
1960	18.665	1,586	4.60	0.25	23.107	4.60	0.25	23.107
1961	19.745	1,647	5.02	0.25	24.875	5.02	0.25	24.875
1962	21.31	1,707	6.83	0.25	32.313	6.	0.25	28.993
1963	22.81	1,767	6.80	0.25	32.363	6.	0.25	29.163
1964	24.555	1,828	7.10	0.25	33.773	6.	0.25	29.373
1965	26.34	1,888	7.47	0.25	35.460	6.	0.25	29.580
1966	28.535	1,948	7.57	0.25	36.139	6.	0.25	29.859
1967	30.675	2,009	7.69	0.25	36.867	6.	0.25	30.107
1968	33.545	2,069	8.11	0.25	38.925	6.	0.25	30.485
1969	36.375	2,129	8.40	0.25	40.434	6.	0.25	30.834
1970	39.955	2,190	8.75	0.25	42.297	6.	0.25	31.297
1971	41.98	2,250	8.16	0.25	40.103	6.	0.25	31.463
1972	44.105	2,310	7.08	0.25	35.957	6.	0.25	31.637
1973	48.195	2,371	7.29	0.25	37.290	6.	0.25	32.130
1974	47.615	2,431	4.48	0.25	25.754	4.48	0.333	19.335
1975	43.79	2,491	1.06	0.25	11.271	1.06	0.35	8.051
1976	47.405	2,552	1.82	0.25	14.710	1.82	0.35	10.507
1977	49.135	2,612	0.48	0.25	9.444	0.48	0.35	6.746
1978	48.85	2,672	0.64	0.25	9.872	0.64	0.35	7.052
1979	51.28	2,733	4.03	0.25	23.625	4.03	0.4	14.765
1980	47.935	2,793	0.28	0.25	7.985	0.28	0.45	4.436
1981	44.525	2,853	−2.43	0.25	−3.477	0.5	0.5	4.121
1982	42.075	2,914	−3.66	0.25	−8.864	0.5	0.55	3.534
1983	41.54	2,974	−5.13	0.25	−14.932	0.5	0.6	3.161
1984	42.87	3,034	−2.75	0.25	−5.348	0.5	0.6	3.188
1985	42.215	3,095	−1.32	0.25	0.176	0.5	0.6	3.106
1986	44.1	3,156	1.18	0.25	10.3094	1.18	0.6	4.2956

TABLE A2. Implicit discount rate

References

Adelman, M.A., *World Petroleum Market*, Baltimore: Johns Hopkins U.P., 1972.

Adelman, M.A., OPEC as a cartel, *OPEC Behavior and World Oil Prices*, ed. by J.M. Griffin & D.J. Teece, London: Allen & Unwin, 1982.

Ball, R., and Marks, R.E., Short-term supply side instability in the oil market, *AGSM Working Paper 86−023*, September 1986.

Blair, J.M., *The Control of Oil*, New York: Pantheon, 1976.

British Petroleum, *BP Statistical Review of World Energy*, London, Annual.

Chichilnisky, G., Heal, G., and Sepahban, A.H., Non-conflicting resource pricing policies in an independent world, *OPEC Review*, 7(4): 330−56, 1983.

Dasgupta, P.S., and Heal, G.M., *Economic Theory and Exhaustible Resources*, Welwyn: Nisbet/Cambridge U.P., 1979.

Griffin, J.M., OPEC behavior: a test of alternative hypotheses, *American Economic Review*, 75(5): 954−63, 1985.

Griffin, J.M., and Steele, H.B., *Energy Economics and Policy*, Orlando (Fla.): Academic Press, 2nd. ed., 1986.

Hotelling, H., The economics of exhaustible resources, *Journal of Political Economy,* 39: 137−175, 1931.

Ivanhoe, L.F., US vs. foreign oil deals, *Oil & Gas Journal*, pp.176−178, November 19, 1984.

Johany, A.D., *The Myth of the OPEC Cartel: the Rôle of Saudi Arabia*, Chichester: Wiley, 1980.

Johany, A.D., OPEC and the price of oil: cartelization or alteration of property rights, in *OPEC: Twenty Years and Beyond*, ed. by R. El Mallakh, Boulder: Westview, 1982.

Kirkby, M.A., and Adams, T.D., The search for oil around the world up to 1999, *Petroleum Times*, 78(1995): November 1, 1974.

Marks, R.E. and P.L. Swan (1987) "Property rights and implicit discount rates in the world oil market," in: *The Changing World Energy Economy: Papers and Proceedings of the Eighth Annual North American Conference, November 10−21, 1986*, edited by D.O. Wood, (Cambridge, Mass.: International Association for Energy Economics), pp.525−530.

Marks, R.E. and Swan, P.L. (1993) "Exhaustibility and the reserves/production ratio," *Economics Letters,* **42**(1): 117−119.

Meade. W.J., The OPEC cartel thesis reëxamined: price constraints from oil substitutes, *The Journal of Energy and Development*, 11(2): 213−242, 1986.

Miller, M.H., and Upton, C.W., A test of the Hotelling valuation principle and the case of the oil and gas companies, *Journal of Political Economy*, 93(1): 1−25, 1985.

Pindyck, R.S., Gains to producers from the cartelization of exhaustible resources, *Review of Economics and Statistics,* 60: 238−251, 1978.

Roumasset, J., Isaak, D., and Fesharaki, F., Oil prices without OPEC: a walk on the supply side, *Energy Economics,* 5(3): 164–170, 1983.

Rustow, D.A., and Mugno, J.F., *OPEC Success and Prospects*, London: Martin Robertson, 1976.

Stiglitz, J.E., Monopoly and the rate of extraction of exhaustible resources, *American Economic Review,* 66(4): 655–661, 1976.

Wiggins, S.N., and Libecap, G.D., Oil field unitization: contractual failure in the presence of imperfect information, *American Economic Review,* 75(3): 368–385, 1985.