"THE ALLOCATION OF PROPERTY RIGHTS TO UNMINED MINERALS ON THE OCEAN FLOOR"

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This paper is circulated for discussion purposes only and its contents should be considered preliminary.

In the first part of this paper it is argued that unregulated development of the minerals on the ocean floor will not be economically efficient. Allocation of property rights to unmined minerals is the administratively cheapest method of securing an efficient outcome. Methods of allocating property rights are then evaluated from the standpoint of maximising certain social welfare functions, embodying various distributional judgements.

A simple rule which the government could follow in auctioning sites is proposed.

The discovery of manganese nodules (containing copper, nickel, cobalt, and manganese) lying on the ocean floors of the world was in the 1890's. However only in the 1960's did recovery become economically viable. As research and exploration proceeded in the 1960's it became evident that nodules were of considerable economic consequence - for example they contain enough copper and nickel to last the world 400 years, at current consumption levels. Now current International Law gives ownership of the nodules to whomsoever can gather them. Thus firms will be free to enter this industry, gathering nodules in whatever quantity they choose, subject only to the tax laws of their home country. Clearly such behaviour will violate the widely expressed distributional judgement that the nodules are the "common heritage of mankind"[2]. However the question I want to raise in the first part of this paper is whether such behaviour will even be efficient. In particular the role of property rights to unmined nodules is discussed. The second part of the paper considers methods of allocating such property rights, in the context of various distributional judgements.

Several writers have recently argued that it is not necessary to allocate property rights to unmined nodules, or to regulate mining in any other way, if our aim is to reach an efficient outcome. Eckert[1] argues that failure to allocate property rights causes inefficiency only if there is a "free-rider" problem or if there is a "common pool" problem. He argues that the "free-rider" and "common-pool" problems are not serious in this case and therefore reaches the conclusion that considerations of efficiency alone do not require the allocation of property rights. Similarly Sweeney et. al.[3] examineswhether market failure will result from the absence of property rights to the ocean floor. Considering "common pool" problems and "claim-jumping" they too conclude

> "In the case of nodule mining ..... unregulated economic activity may be expected to yield an efficient outcome" (p. 181.)

I think there are two characteristics of this industry, not mentioned by earlier writers, which suggests that we will not expect nodules to be developed in an economically efficient way, without some form of property rights.

The first significant characteristic of this industry is that there are a fixed quantity of nodules available. Thus the efficient development path is the solution to the problem of allocating this fixed quantity of inputs over time. Although earlier writers have not made this definition of "efficient" explicit, I take the "efficient" development of the nodules to be that which maximises a social welfare function which is a simple sum of consumers surplus and producers surplus, i.e.

$$W = \sum_t \left[\int_0^{Q_t} P_t \; dQ - x.Q_t \right] \frac{1}{(1+R)^t} \qquad (1)$$

where
R = discount rate
x = average costs of extraction of one unit = marginal costs of 1 unit
P_t = price of nodules in year t.

Assume a linear derived demand schedule for nodules, which is further assumed to be identical each year. This is derived from the net demand schedules (i.e. $D^A(P) - S^A(P)$, where $S^A(P)$ is the land based supply of mineral A) for each metal. Let this derived demand schedule be $Q_t = a + bP_t$

$$\therefore \quad P_t = \frac{Q_t}{b} - \frac{a}{b} \tag{2}$$

$$\therefore \quad \int_0^{Q_t} P_t \, dQ = \int_0^{Q_t} \left(\frac{Q_t}{b} - \frac{a}{b} \right) dQ$$

$$= \frac{Q_t^2}{2b} - \frac{a}{b} Q_t$$

$$\therefore \quad W = \sum_t \left[\frac{Q_t^2}{2b} - \frac{a}{b} Q_t - x.Q_t \right] \cdot \frac{1}{(1+R)^t} \tag{3}$$

Now W must be maximised subject to the constraint that $\Sigma Q_t = \bar{Q}$ where $\bar{Q}$ = stock of nodules which are available. Consider the case where

$$Q_t = a + b P_t \quad , \qquad t = 1, 2$$
$$Q_t = 0 \qquad\qquad \text{for all other } t.$$

This is sufficient to bring out the central issues, and permits diagramatic interpretation.

Thus the problem facing a social planner who is concerned only with efficiency is to maximise L, where :-

$$L = \frac{Q_1^2}{2b} - \frac{a}{b} Q_1 - x.Q_1 + \left[\frac{Q_2^2}{2b} - \frac{a}{b} Q_2 - x.Q_2 \right] \frac{1}{(1+R)}$$

$$+ \lambda (\overline{Q} - Q_1 - Q_2) \qquad (4)$$

$$\frac{dW}{dQ_1} = \frac{Q_1}{b} - \frac{a}{b} - x - \lambda = 0 \qquad (5)$$

$$\frac{dW}{dQ_2} = \left[\frac{Q_2}{b} - \frac{a}{b} - x \right] \frac{1}{(1+R)} - \lambda = 0 \qquad (6)$$

$$\frac{dW}{d\lambda} = \overline{Q} - Q_1 - Q_2 = 0 \qquad (7)$$

From (5) ; $p_1 - x - \lambda = 0$

From (6) ; $p_2 (1+R) - x (1+R) - \lambda = 0$

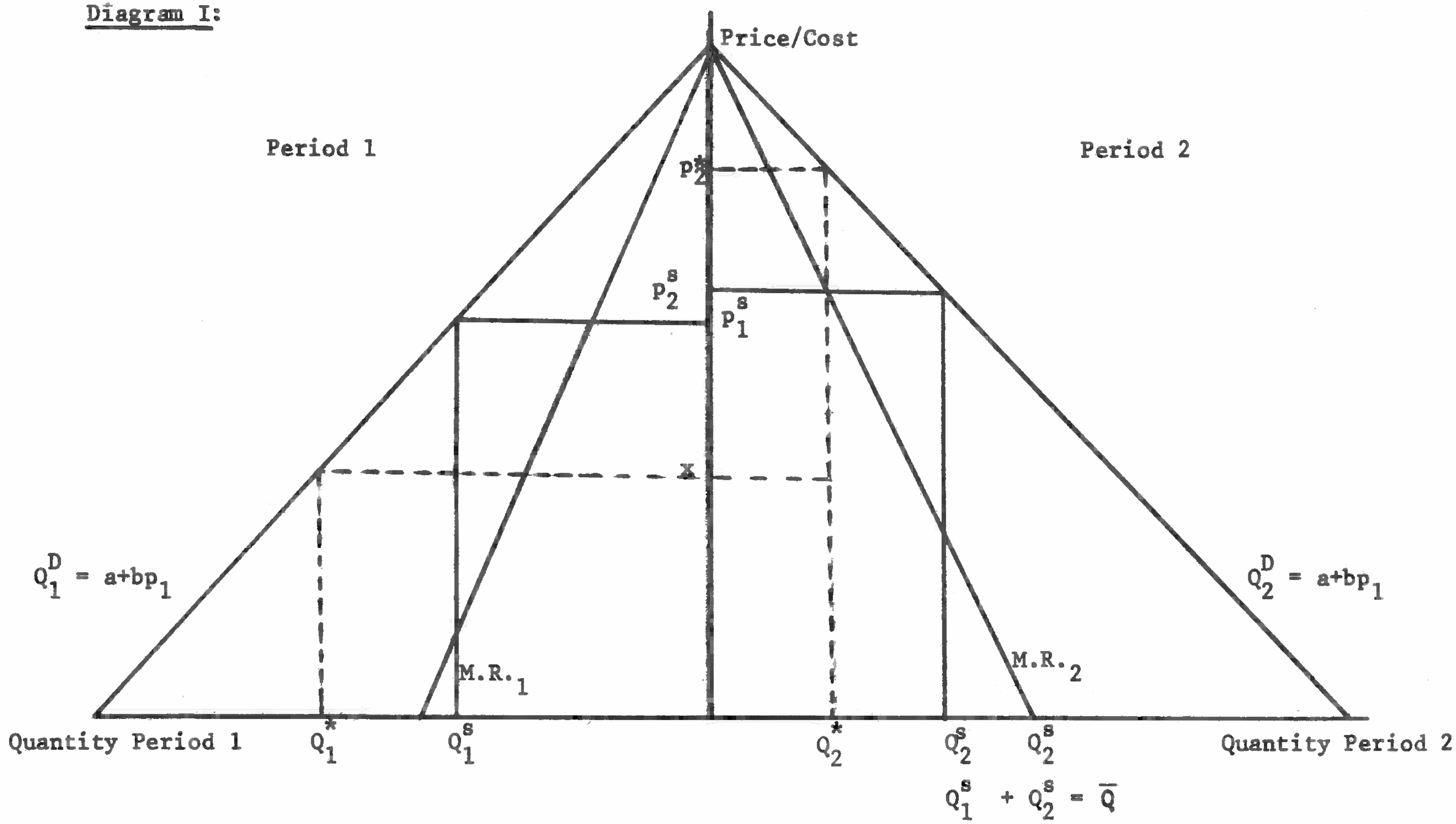
$$\therefore \quad (p_2 - x) = (p_1 - x)(1 + R) \qquad (8)$$

$$\lambda = p_1 - x \qquad (9)$$

Thus the efficient quantity vector is (Q_1^s, Q_2^s) which implies a price vector (p_1^s , p_2^s) where $p_2^s = (p_1^s - x)(1 + R) + x$ (10)

(see diagram I)

Diagram I:


Price/Cost
Period 1
Period 2
p_2^*
p_2^s
p_1^s
x
$Q_1^D = a+bp_1$
$Q_2^D = a+bp_1$
M.R.1
M.R.2
Quantity Period 1
Q_1^*
Q_1^s
Q_2^*
Q_2^s
Q_2^s
Quantity Period 2
$Q_1^s + Q_2^s = \overline{Q}$

Now suppose that there is no system of property rights and that any firm that wishes is free to enter the nodule industry. Also assume that the costs of storage of nodules is infinite so that they must be sold in the period in which they are mined.

Then industry equilibrium in the first period requires price equal to average cost, $p_1 = x$, where quantity Q_1^* will be mined. Price next period must be p_2^* where $Q_2^* = \bar{Q} - Q_1^*$; $Q_2^* = a + b\ p_2^*$.

Thus the fixed resource is exploited too quickly without property rights to the unmined nodules. In the multi-period case this argument would imply that the industry produces up to the point where $p_t = x$, for all t but the last, the situation in the last period of the multi-period case would be that of period 2 here.

In fact, we are likely to have an International Registry Authority, which will control entry. Suppose it licenses enough firms, such that quantity Q_1^* can be mined in the first period. Then, even if entry to the industry is thereafter closed, competing firms will still mine Q_1^* in t_1. This is because any nodules not mined this period by a particular firm will not automatically accrue to it next period. It will only capture $\frac{1}{k} \cdot \Delta N$ next period, if there are k firms, where ΔN is the cutback in one firm's production in t_1.

I.e. one firm would only have an incentive to reduce output in t_1 if the price vector was such that :

$$(P_2 - x)\ \frac{1}{k} \ > \ (P_1 - x)\ (1 + R)$$

The incentives to cartelization in this case will be strong. In addition to the fact that profits can be increased as the cartel faces a marginal revenue different from price, as the cartel expands the condition for a re-allocation of output between t_1 and t_2 increasing profits becomes:

$$(P_2 - x) \cdot \frac{n}{k} > (P_1 - x)(1 + R)$$

where n = number of firms in the cartel.

As n increases, it becomes more likely that profits can be increased by contracting output in t_1. Cartelization therefore is in the public interest, at least up to some point. If $n = k$ then the resource will be exploited too slowly, compared to the social optimum (see Appendix 1). Thus for some n, the cartel will produce a production vector very close to the social optimum. (Since cartelization is not a continuous process, it will be unlikely to yield the exact optimum). This result may not carry through into a multi-period model, for the cartel may fear its breakdown in the future. Property rights assure the firm of its claim to future nodules, whilst it cannot be so confident in its membership in the same cartel twenty years ahead.

If instead the ownership of the unmined nodules were divided up between k price-taking firms then the output vector of the industry would be identical to that picked by the social planners providing the same discount rate is used. The price vector expected by each firm must satisfy:

$(P_2 - x) = (P_1 - x)\ (1 + R)$, where R = the best yield on a 1 period investment available to the firm. (If $P_2 > (P_1 - x)\ (1 + R) + x$ then every firm would have an incentive to produce its stock of nodules in period 2. Thus P_2 would fall and P_1 rise. And conversely if $P_2 < (P_1 - x)(1 + R) + x)$. Thus if the discount rate used by firms equals that used by the government, then perfect competition leads to the socially optimal rate of exhaustion.

Now before we state the size of the loss resulting from the failure to allocating property rights, in the competitive case, we must deal with one other problem. Industry profits in the second period are $(P_2^* - x).Q_2^*$. Now since entry to this industry is free, one would expect entry to continue until this "excess" profit was dissipated. This would be through congestion - too many miners trying to work a small number of nodules.

Now the social cost of failure to allocate property rights, in the competitive case, is given by :-

$$\text{Social Cost} = \frac{1}{(1+R)} \int_{Q_2^*}^{Q_2^s} (p - x)\ dQ - \int_{Q_1^s}^{Q_1^*} (p - x)\ dQ \qquad (11)$$

$$+ \quad (p_2 - x)\ .\ Q_2^* \ \frac{1}{(1+R)}$$

If for any other (political) reasons we did not want to allocate property rights, there is an alternative policy which will reduce the social loss defined by (11). The International Community could levy a per unit royalty, $t_1 = p_1^s - x$ in the first period, and $t_2 = p_2^s - x$ in the second period. The problem with this is that in general, a different level of royalty would be required in each period in the multi-period case. In order to perform the calculation the government would have to obtain from firms information on production costs; and this would lead to the usual problems of how to persuade firms to reveal costs truthfully. Thus allocating all property rights is the cheapest method, for the government, of ensuring an efficient outcome.

Now allow for arbitrage of mined nodules between period 1 and period 2. Assuming away adjustment costs, all the nodules will be mined in the first period if there are no property rights. They will then be sold over the two periods such that $p_2 = p_1 (1 + R) + Z$

$$p_2 = p_1 (1 + R) + Z \tag{12}$$

where Z = unit storage costs for 1 period. One would expect any pure profit to be dissipated by congestion in the first period. Thus the social cost in this case, compared to the social planners outcome is,

$$\text{Social loss} = \frac{1}{(1+R)} \int_{Q_2^a}^{Q_2^s} (p - x)\, dQ + (rx + Z).\, Q_2^a$$

$$- \int_{Q_1^s}^{Q_1^a} (p - x)\, dQ + \text{net profit} \tag{13}$$

where, net profit $= Q_1^a (p_1^a - x) + \frac{1}{(1+R)} Q_2^a \cdot p_2^a - x.Q_2^a - Z.Q_2^a$

$$Q_1^a = a + bp_1^a$$

$$Q_2^a = a + bp_2^a$$

Comparing (10) and (12) we see that $p_2^a > p_2^s$ and $p_1^a < p_1^s$.

The International Authority would have scope for encouraging or discouraging arbitrage (For example, by itself creating storage facilities, loans, etc.) Whether arbitrage should be encouraged or not, in the case where property rights are not allocated, depends on comparison of expressions (11) and (13), computed for the multi-period case. A situation where property rights are not allocated, but there is arbitrage is always inferior to one where property rights <u>are</u> allocated. This is both because of storage costs, and the fact that it is better to incur costs later than early, i.e. given a consumption vector, we don't want to incur production costs earlier than we have to.

Property Rights and Choice of Technology

There is another important characteristic of this industry, in addition to that discussed above, which suggests that unregulated development of nodules will not be efficient. The quantity of nodules recovered from a particular mine site depends upon :-

1. The pick up efficiency of the dredge head.

2. The percentage of the site actually traversed by the dredge head.

Number 1 above varies from 30% to 70% depending upon the quality of the dredge head; number 2 varies from 35% to 55% depending on the quality of the guidance system [4]. Thus the fraction of nodules recovered on a particular site varies between 10.5% and 38.5%, depending on the choice of technology. Above we assumed the stock of nodules, $\bar{Q}$, was given. Now we must recognise the fact that the total stock of nodules, which it will be feasible to recover, depends on the choice of technology.

In addition future costs of production will depend on the choice of technology to-day. Firstly, the percentage of nodules picked up on each site will determine how long the virgin sites will last, given the output vector. Mining sites that have already been worked in part is more expensive than mining virgin sites, since "bald" patches will continually be encountered with the former. Thus the more we spend on mining efficiently to-day, the lower will be basic extraction costs in some later years. Although it will be a very long time before <u>all</u>

virgin sites are exhausted, the number of good sites will be exhausted far more quickly ("Good" sites are those where the water is less deep and the bottom even). Thus the lower is the percentage of nodules on good sites which are actually collected, the sooner will the industry be faced with the choice of either moving to second generation sites, or re-working first generation sites.

Clearly "efficient" development of the nodules implies some particular expenditure on mining sites carefully. This expenditure is found by solving the following problem :-

Maximise welfare, as defined by (3) above, subject to :-

$$Q_t = g\left(J_{t-1} \ldots J_{t-t} , \sum_{T=1}^{t} Q_{t-T}\right) f(K_t) \qquad (14)$$

where

J_t = expenditure, in year t, on technology which determines the percentage of nodules recovered from particular site.

K_t = expenditure, in year t, on basic mining equipment to "produce" nodules.

Q_t = Output of nodules in year t.

(i) $\frac{dQ_t}{dJ_t} = 0 \quad \forall_t$ by assumption

(ii) $\frac{dQ_t}{dJ_{t-T}} > 0$ for some t and for some $T = 1 \ldots. t$

(iii) $$\frac{dQ_t}{dJ_{t-T}} = 0 \quad \text{otherwise}$$

(iv) $$\frac{dQ_t}{d(\sum_{T=1}^{t} Q_{t-T})} < 0 \quad \text{for} \quad t > \text{some} \quad t'$$

(v) $$\frac{dQ_t}{d(\sum_{T=1}^{t} Q_{t-T})} = 0 \quad , \quad t < t'$$

This is a fairly lengthy dynamic programming problem. However if we take $N = 2$, then we can easily derive marginal conditions for maximising W which capture the essence of the problems and are easy to interpret. The problem of the social planner is to maximise Π, where

$$\Pi = \frac{Q_1^2}{2b} - \frac{a}{b} Q_1 - rK_1 - j.J_1 + \frac{1}{1+R} \left[. \frac{Q_2^2}{2b} - \frac{a}{b} Q_2 - rK_2 - j.J_2 \right] \tag{15}$$

$$\frac{d\Pi}{dJ_1} = \frac{1}{1+R} \left[\frac{1}{b} Q_2 \cdot \frac{dQ_2}{dJ_1} - \frac{a}{b} \frac{dQ_2}{dJ_1} \right] - j = 0$$

$$\frac{dQ_2}{dJ_1} \cdot \frac{Q_2}{b} - \frac{a}{b} \frac{dQ_2}{dJ_1} = j\ (1 + R)$$

$$\therefore \quad \frac{dQ_2}{dJ_1} = \frac{j\ (1 + R)}{P_2} \tag{16}$$

Along with the other marginal conditions (16), will implicitly define the optimal expenditure on mining a site carefully. We will also be able to solve for Q_1^s, Q_2^s. If we define the absolute physical quantity of nodules on the ocean floor to be $\overline{Q}$, then $\frac{Q_1^s + Q_2^s}{\overline{Q}}$ is the percentage of nodules picked up on the average site.

Now consider the development of the industry by competitive firms, without property rights, assuming free entry to the industry. Free entry implies that $p_t = C(Q_t)$ for all t; where C = minimum average cost for producing Q_t - i.e. the average costs of producing nodules by firms of the efficient size, using basic mining equipment only $(J_t = 0)$. If $p > C(Q_t)$ at any time because all firms in the industry were being "careful" then new firms would enter the industry in that period, driving price down and forcing the "careful" firms to make less than normal profits. Thus equilibrium of the industry implies that the least efficient technology, in terms of percentage of nodules collected from any site, will always be used.

Even if entry to the industry were restricted, we would not expect to find firms mining oprimally. Any firm who mines carefully in one particular year will find itself with exactly the same production possibilities in future years, as do other firms who took no care. Without property rights the virgin sites, which are saved as a result of one firm making more intensive use of a few sites, do not accrue only to the careful firm. Similarly the effect of increased care taken by one firm, on the total stock of nodules, will benefit all firms equally. i.e. An individual firm faces the production function:-

$$q_{ti} = g(J_{t-1} \ldots\ldots J_{t-t}, \sum_{T=1}^{t} Q_{t-T}) \, f(k_{ti}) \text{ where } k_{ti} =$$

quantity of capital used by firm i in year t.

q_{ti} = output of firm i in year t.

The basic problem then is that of externalities. The single firm only captures $\frac{1}{K}$ of the benefits of its expenditure, where K is its market share. Now allocation of property rights is an easy way to internalize the benefits of more careful mining. With property rights, each firm would face the problem of maximising the present value of profit subject to

$$q_{ti} = g\,(h_{t-1li} \ldots\ldots h_{t-t}, i, \sum_{T=1}^{t} q_{t-T}, i) \quad f(k_{ti}) \qquad (17)$$

where q_{ti} = production of firm i in year to

h_{ti} = expenditure on mining carefully, by firm i in year t

k_{ti} = capital used by firm i in year t.

The maximand of the competitive price taking firm is the same as the social planner who is only concerned with efficiency. Thus the structure of the problem facing the firm with property rights is the same as the problem facing the social planner. If (17) is homogeneous of degree less than or equal to 1 in all the arguments then this industry equilibrium will be efficient.

Again consider alternative methods of securing an optimum. In addition to calculating an annual royalty on the industry (as described above) it would be necessary to subsidise the use of J_t by competitive firms. However this again brings us back to the problem of persuading firms to truthfully disclose costs. The subsidy could be based either on expenditure, or on results (i.e. percentage of nodules picked up). Suppose it were based on expenditure. Any mining rig is a composite of K_t and J_t, and therefore firms would have an incentive to claim that a larger part of total capital is unproductive, in terms of current output, than is true, in order to claim a larger subsidy. Alternatively suppose the government checked the percentage of nodules which had been collected from a site after its use, and based the subsidy upon this figure. This would then require that the firms truthfully reveal to the government how much it cost them to increase the percentage of nodules collected on a site by a particular amount. In addition it would be very expensive to examine every site after use. Thus the allocation of property rights is the easiest way, in terms of information required, administrative computation time, and policing, to ensure efficient development of the nodules.

Methods of Allocating Property Rights

Having argued that allocating property rights to unmined nodules is the best way to ensure efficient use of the nodules, we must now consider how to allocate such rights. The best method of allocation will depend in part on the social welfare function. Suppose the social welfare function is a weighted sum of consumers surplus, profit, and tax revenue (if any), i.e.

$$\omega = \omega_1 CS + \omega_2 . \Pi + \omega_3 . T$$

where CS = present value of consumers surplus

Π = present value of profit of mining companies

T = present value of Tax revenue received by international authority.

ω_1, ω_2, ω_3 are weights on each type of income flow, reflecting the governments distributional judgements. Now we may distinguish 3 cases :-

<u>Case (1):</u> $\omega_1 = \omega_2 = \omega_3$

This is a Social Welfare function which is concerned only with efficiency. In this case any method of dividing the property rights to all unmined nodules between a sufficient number of competitive (i.e. price-taking) firms will maximise ω.

<u>Case (2):</u> $\omega_1 = \omega_3 > \omega_2$

This social welfare functions weights more highly a pound taken by the international authority, than a pound of profit earned by the miners. Now if we auction all the sites, so that the receipts from the auction are the equivalent of tax revenue (in the sense that it is cash available for distribution to L.D.C.'s) this will maximise ω providing:- (a) There are a large number of potential mines.

(b) Each firm is perfectly informed about future costs and revenues.

(c) There are perfect capital markets.

(d) Firms use the same discount rates as the Government.

The implications of relaxing these assumptions are discussed below.

<u>Case (3):</u> $\omega_3 > \omega_1 > \omega_2$

Here the Social Welfare Function of the international community weights a pound of tax revenue more highly than a pound of consumers surplus. This might be because, in general, the consumers of the minerals dwell in M.D.C.'s, whilst the recipients of the tax revenue would be L.D.C.'s. Maximising ω would now require the levying of a royalty at a high level in the early years, and then at gradually falling rates in later years. Having announced the royalty levels for each future period, the sites would again be auctioned. Again, given assumptions (a), (b), (c), (d), above, for any ω_3, ω_1, ω_2 we can set the appropriate royalty schedule to maximise ω. If in the limit, $\omega_3 = 1$, $\omega_2 = \omega_1 = 0$, then the government would have to levy a royalty such that the same quantity vector as offered by a monopolist would be induced (see Appendix I). The effect of this royalty will, in each case, be to retard the development of the nodules.

We must now examine the effects of removing the assumption that firms are perfectly informed about future costs and benefits. Assume that firms deal with uncertainty in the following way. They form an expected value of net benefits in any year from developing a site. Then they add a risk premium to the discount rate when they calculate the net present value of the profit on a particular site. If all the sites are identical then the price bid today for a site, regardless of when it is to be used, will be V_f, where V_f is the present value of the profit on developing the site. Clearly sites will be exhausted over time in such a way that the present value of profit on all sites $= V_f$; otherwise sites could be re-allocated over time to increase profits.

$$\text{Let } R = r + k, \qquad (24)$$

where r = firms basic discount rate reflecting opportunity cost of capital.

k = risk premium

R = discount rate used for actual calculation of present value.

Then if the expected value of profit in any one year = $\overline{V}_t$, from a particular site, then the present value of this profit is V_f; $V_f = \sum_t \overline{V}_t \cdot \frac{1}{(1+R)^t}$. If we assume that each site is used within one year, then the present value of a site to be used in year t, is

$$V_f = \overline{V}_t \cdot \frac{1}{(1+R)^t} \qquad (25)$$

As argued above, profit maximisation requires the allocation of all sites over time so that $\overline{V}_t$ is such that $V_f = \overline{V}_t \cdot \frac{1}{(1+R)^t}$ for all t. If all sites are auctioned today the revenue received by the international community will be

$$T' = \sum_t V_f \cdot S_t^* \qquad (26)$$

where S_t^* = number of sites to be used in year t. The vector $(S_1^* \ldots . S_N^*)$ is implied by the solution to the overall profit maximisation problem faced by price-taking firms with property rights.

Alternatively, suppose that the authority only auctioned S_t^* sites each year. The expected present value of the revenue would be

$$T^* = \sum_t V_f (1+R)^t \cdot S_t^* \cdot \frac{1}{(1+r)^t} \qquad (27)$$

assuming the government is risk neutral.

$$\therefore \quad T^* = \sum_t V_f \left[\frac{1+r+k}{1+r}\right]^t \cdot S_t^*$$

$$= \sum_t V_f (1+0.x)^t \cdot S_t^* \qquad (28)$$

where $(1+0.x) = \left[\frac{1+r+k}{1+r} \right] \quad , \quad x > 0$

comparing (28) and (26) it is clear that the expected present value of revenue, from auctioning sites gradually, is greater than the revenue that would be received if all sites were auctioned today. If tax revenue is valued more highly in the social welfare function, than profit, then the government should only auction as many sites as are actually to be developed in the same year.

One can also analyse the two alternatives, auction all sites today, or auction bit by bit, in terms of ex poste outcomes. This also allows two assumptions in the above to be dropped - that the government is risk neutral and that firms allow for uncertainty by simply using a higher discount rate. However we must make a further, plausible, assumption about the Social Welfare Function. Assume that "excess" profits (defined below) have a weight of zero. However normal profits have a weight equal to tax revenue; the community has no desire to collect more tax revenue at the expense of normal profits, since this will be a disincentive to entry in the long run, or, worse, lead to resource using bankruptcies. There are two possible outcomes if the community delays auctioning sites, until they are due to be used.:-

(i) $V_t^g > V_f \; (1+r)^t$

(ii) $V_t^g < V_f \; (1+r)^t$

where V_t^g = demand price for a site in the year when it is to be used. Define normal profits to be $\overline{V}_t - V_t^g$. (By this definition we are including the risk premium for the actual development, but excluding a return to holding a "risky" asset over time, until it is to be used.

The latter return has a weight of zero in the social welfare function, because it rewards a factor service (risk-bearing) that could have been supplied costlessly by the community). If (i) holds then Social Welfare is higher as a result of delaying the auction - because tax revenue is higher by the same amount that "excess" profits are lower.

If (ii) holds then social welfare is no lower, because, had all sites been auctioned earlier, tax revenue would have been higher, but at the expense of normal profits.

Thus in terms of outcomes, the Social Welfare may be higher, and cannot be lower, if we delay auctioning sites until they are to be developed.

This problem of risk averse bidders pushing prices today, for sites to be developed in the future, to very low levels is made worse by the following state of affairs. There is a small group of well informed bidders - the six or seven firms which have actually carried out surveys and undertaken some exploratory mining. There are a large number of much less well informed potential developers, who would put in bids for sites. Further it is reasonable to assume that well-informed firms have limited access to capital markers, so that they could only take up a small fraction of the total number of sites offered, if <u>all</u> were auctioned today. If the less well informed have a probability density function of over site values which is a mean preserving spread of that of the informed, then they will bid an even lower price than the informed. That is, if the "uninformed" are risk-averse, and they perceive the risk as larger than do the "informed" then they will require a larger expected return for bearing it. In fact if the auction takes the form of competing public bids, the price bid for sites may never go above the price bid by the uninformed, since the demand for sites by the informed is for less than total supply. Thus we certainly should never auction more sites than could be taken up by "informed" buyers.

A Rule for the Auctioning of Sites

The underlying principle in the above arguments about delaying the auctioning of sites, is that risk bearing is a factor service which can be supplied costlessly, in this industry, by the government. There is no point in paying individuals to bear the risk of holding nodule sites for long periods.

Having argued that the government should allocate sites gradually as they are required, we must establish a rule for the government to follow in choosing how many sites to auction each year. Clearly we don't want to require the government itself to calculate the optimum development path, $(S_1^* \ldots\ldots S_N^*)$ since this involves us in the usual problems of how to encourage firms to reveal their costs of production. However there is a simple rule that the government can follow. Suppose it auctions S_1^g greater than S_1^*. Then some sites, $S_1^g - S_1^*$, will be held by speculators amd not in fact be developed today. (If all S_1^g were used, this would push metal prices down so that the profit on each site would be lower than if they had been held until prices were higher in later years). There will be some loss to the government, because of speculative holdings, as described above. But if one year it observes an increase in the (small) number of speculative holdings, this will convey the information that it auctioned too many sites that year. Thus the following year it would auction slightly fewer. And if the size of the speculative pool decreased in any year, then slightly more sites would be auctioned in the next year. In this way, by allowing a small pool of speculative holdings, the government does not itself have to calculate the optimum number of sites to release each year. The size of the pool of speculative holdings would depend on the absolute size of the "mistake" $|(S_t^g - S_t^*)|$ that the authority thinks it might make.

At this point a comment about "work requirements" is relevant. Several writers have discussed at length the damaging effects of work requirements, rarely finding anything to say in their favour. Here we have another problem they cause. Work requirements undermine the above simple rule. If speculators are not to be allowed to arbitrage away the governments mistakes, then if the "wrong" number of sites is auctioned then this will be transmitted directly into the "wrong" rate of development of the nodules. And since the government no longer can use the simple rule "base year t's allocation on the size, and change in size, of last years speculative holdings" the government will now have to obtain information from firms about costs. So not only will it be harder to calculate the correct number of sites to auction, but also, to the extent mistakes are made, they will not be compensated for in the private sector. Thus one would have to attach a very large negative weight to profit of speculators, in the social welfare function, before one wanted to insist on work requirements.

There is one exception to this argument. The costs of production of miners in the first period are likely to be much higher than in all later periods, because the technology will be being developed.

In particular suppose there are fixed costs, γ, involved in starting the industry. If S_1^* sites are to be developed in the 1st period (S_1^* defined as above) then $\frac{\gamma}{S_1^*}$ is the fixed cost per site. (Since γ is a fixed cost for the industry in year 1, it will not effect the optimal development path in any way). If all expenses, γ, can be patented, and therefore recovered from other firms, we have no problem. However if they cannot, then site prices will have to be lower than otherwise by the full value of $\frac{\gamma}{S_1^*}$. In general expected site prices (which are equal to expected net profit on the site) rise according to

$$V_t = V_0 \, (1+R)^t \tag{32}$$

(from (29) above) where V_0 = site price in 1st period. V_t = expected site price in year t. Taking account of the above problem, site prices will rise over the 1st two periods so that

$$V_1 = V_2 \frac{1}{(1+R)} - \frac{\gamma}{S_1^*} \tag{33}$$

Thus the expected value of speculators profit is,

$$Z_1 = V_1 \, . \, k + \frac{\gamma}{S_1^*}$$

Since $V_1 \, . \, k$ is supply price of speculative funds, $R = r + k$, to this industry, there will clearly be excess demand from speculators for sites if (33) holds. However if this bids up prices such that $V_1 > V_2 \frac{1}{(1+R)} - \frac{\gamma}{S_1^*}$, then potential developers will withdraw from the market. If this happens site values will not rise as speculators anticipated. The outcome of this unstable situation will depend on how well informed speculators are about firms development costs. It might well be, for example, that they bid up prices such that $V_1 > V_2 \frac{1}{1+R} - \frac{\gamma}{s_1^*}$, not realizing this has choked off demand by actual miners. So the development of the industry would be hampered, and speculators make losses. It might well be advantageous to introduce work requirements, in the first period only, to get around this problem.

Policy Conclusions

Allocation of property rights to unmined nodules on any site which a miner is working, or about to work, on the terms described above, is necessary in order to provide the miners with an incentive to treat the nodule areas as the scarce resource that they in fact are. Whatever, other decisions are reached by the United Nations about the need for quantity controls, levels of royalty tax etc., the allocation of unconstrained property rights to unmined nodules should be a component of the final regime.

APPENDIX I

A monopolist maximizes profits over the two periods subject to the demand functions :

$$D_1 = a + bP_1$$

$$D_2 = a + bP_2$$

Average costs are constant over both periods, and independent of the allocation of production between the two periods. Average cost = x. There is a fixed quantity of resource = N. Profit maximization implies that output be allocated such that :

$$(MR_2 - x) = (MR_1 - x) \quad (1+R) \qquad (70)$$

If the industry was composed of perfectly competitive firms, the production would be allocated between the two periods, such that :

$$(P_2 - x) = (P_1 - x) \quad (1+R) \qquad (71)$$

Now suppose the price vector did satisfy expression (71), when the industry was controlled by a monopolist. Then if we can show :

$$(MR_2 - x) > (MR_1 - x) \quad (1+R)k$$

given expression (71), it follows that the monopolist is not maximizing profits. He should allocate more production to the second period,

MR_2 down and MR_1 up. Proof that $(MR_2 - x) > (MR_1 - x)\ (1+R)$, (72), if expression (71) holds :

$$D_1 = a - bP_1$$

$$\therefore \quad P_1 = \frac{a}{b} - \frac{Q_1}{b}$$

$$\therefore \quad MR_1 = \frac{a}{b} - \frac{Q_1}{b}$$

$$\therefore \quad MR_1 = P_1 - \frac{Q_1}{b} \tag{73}$$

we must show, substituting expression (73) into expression (72)

$$P_2 - \frac{Q_2}{b} > \left[P_1 - \frac{Q_1}{b} - x\right] (1+R) + x$$

$$\therefore \quad (P_1 - x)\ (1+R) + x - \frac{Q_2}{b} > P_1 - x)\ (1+R)\ - \frac{Q_1}{b}\ (1+R) + x$$

$$\therefore \quad - \frac{Q_2}{b} > - \frac{Q_1}{b}\ (1+r)$$

$$(1+r)\ Q_1 > Q_2 \tag{75}$$

Since we know $Q_1 > Q_2$, if price is to rise next period, clearly expression (75) is true. So, providing the monopolist does mine all the resource, N, he will produce relatively more in the second period, compared to the competitive industry.

Clearly he will not produce in either period beyond the point where M.R. = x, and so he <u>may</u> not exploit all the resource. In this case, the price would be constant in both periods and so $MR_2 = MR_1$. (76). Thus if he exploits all the resource condition, expression (70) holds and if he does not, then condition (76) holds.

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