The Economics of Overexploitation

Severe depletion of renewable resources may result from high discount rates used by private exploiters.

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Renewable resources, by definition, possess self-regeneration capacities and can provide man with an essentially endless supply of goods and services. But man, in turn, possesses capacities both for the conservation and for the destruction of the renewable resource base.

Indeed, man's increasing capacity to seriously deplete the world's natural resources appears to be reaching a critical stage (*1*); if this is not imminent for the nonrenewable resources (*2*), it certainly appears so for many of the renewable ones (*3*). The problems of environmental pollution that loom so large today, for example, often result from a process of overexploitation of the regenerative capacity of our atmospheric and water resources. Economists lately have devoted much attention to environmental questions (*4*), and most are agreed that "externalities"—that is, effects not normally accounted for in the cost-revenue analyses of producers—are the leading economic cause of pollution and the destruction of natural beauty.

Animate resources, or biological resources, are also subject to serious misuse by man. An accelerating decline has been observed in recent years in the productivity of many important fisheries (*5*), particularly the great whale fisheries and the famous Grand Banks fisheries of the western Atlantic, as well as the spectacularly productive Peruvian anchovy fishery (*6*). As technology improves and demand increases, so the pressure on renewable resources grows more severe. The long-recognized need for effective international regulation of fisheries has never been so pressing as it is today.

A prerequisite for effective regulation is a clear understanding of the basic reasons for overexploitation, and in this regard the outstanding article by Hardin (*7*) on "The tragedy of the commons" has been a positive asset, even though economists have long been aware of the common property problem in fisheries (*8*). Indeed, in concentrating their attention on the problems of competitive overexploitation of fisheries, economists appear to have largely overlooked the fact that a corporate owner of property rights in a biological resource might actually prefer extermination to conservation, on the basis of maximization of profits (*9*). In this article I argue that overexploitation, perhaps even to the point of actual extinction, is a definite possibility under private management of renewable resources.

The implications of this argument for successful international regulation would seem to be that, if it is assumed that society wishes to preserve the productivity of the oceans and to prevent the extermination of valuable commercial species, control of the physical aspects of exploitation is essential. In particular the popular idea of maximum sustainable yield should be generally adopted, at least in the sense of setting an upper limit on the allowable degree of exploitation. Only a dire emergency in local food supply should be considered as a valid reason for temporarily running down the basic stock of a biological resource.

Antarctic Blue Whale Fishery

In developing the economic theory of a biological resource, I take as an example the Antarctic blue whale population. No economic analysis of whaling as such has yet been published, to my knowledge. Certainly, the complete failure of the International Whaling Commission to carry out its mandate to protect and preserve the whale stocks has not been convincingly explained on economic grounds.

A committee appointed by the International Whaling Commission (*10*) estimated in 1964 the net reproductive capacity, in terms of net recruitment of 5-year-old blue whales, as a function of the breeding stock of this species. Their graph, which except for the lower end from 0 to 30,000 whales was little more than an educated guess, is shown in Fig. 1. It appears to indicate a maximum sustainable yield of about 6000 blue whales per annum, but more recent information suggests that this estimate may have been somewhat too high (*11*).

Figure 2 shows the annual blue whale catch (*12*), which expanded rapidly in 1926 following the construction of the first modern stern-slipway factory ships, and ended officially in 1965 when the International Whaling Commission agreed to protect the species. At that time the remaining population was believed to be less than 200 whales, but later estimates have been more optimistic, with the stock in 1972 estimated at about 6000 blue whales (*11*). I return to the case of the blue whales after a general analysis of the economics of biological resources.

Economic Rent

The most commonly encountered proposal for managing a biological resource is to maximize the sustained yield. Indeed, this was the management scheme suggested by the committee to the Whaling Commission (*10*): "The greater the reduction of the present quota, the more rapidly will whale stocks rebuild to the level of maximum sustainable productivity." Economists, however, have taken exception to such proposals (*8*): "Focusing attention on the maximization of the catch neglects entirely the inputs of other factors of production which are used up in fishing and must be accounted for as costs."

Indeed, economists have generally suggested adopting the maximization of economic rent as a management policy. The term economic rent refers to the regular income derived from an endurable resource; it refers to net income, or excess of revenue over costs. Since there is a variety of management possibilities for most resources, it is

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worthwhile to enquire which policy will produce the maximum rent.

In order to obtain a simple mathematical model, suppose that the net recruitment to a particular resource stock of size x is given by a quadratic expression:

$$y = f(x) = Ax(\bar{x} - x) \quad (1)$$

where $A > 0$ is a constant, and $\bar{x} > 0$ represents the natural equilibrium population. The blue whale curve (Fig. 1) has roughly this form, which is related to the logistic equation of theoretical biology:

$$dx/dt = Ax(\bar{x} - x)$$

where t is time.

We also suppose that the net recruitment is the same as (or proportional to) the sustainable yield from a population of size x.

The economic components of our model consist of a constant price $p > 0$ per unit of harvested stock, and a unit harvesting cost $C(x)$ that depends on the population size x. The simplest assumption is that this unit harvesting cost is proportional to the density of the population; in the case of pelagic or demersal fish that are more or less uniformly distributed over their range, this assumption would mean simply that $C(x)$ varies inversely with x. Thus, the total cost of harvesting the sustainable yield $y = f(x)$ would be (approximately)

$$C = By/x = AB(\bar{x} - x) \quad (2)$$

where B is the unit cost coefficient. More general forms of the cost function are considered below.

What sustainable yield, at what population x, gives rise to the maximum rent? Since rent is the difference between revenue R and cost C, the problem is to maximize the expression

$$R - C = pAx(\bar{x} - x) - AB(\bar{x} - x) \quad (3)$$

The maximum occurs when $x = \hat{x}$, where (see Fig. 3)

$$\hat{x} = \frac{\bar{x}}{2} + \frac{B}{2p} \quad (4)$$

provided this expression is less than the equilibrium level $\bar{x}$. (The case $\hat{x} > \bar{x}$ corresponds to the case of negative rent $R - C$ for all populations x; in this case the resource is of no economic value.)

It is clear from Eq. 4 that the rent-maximizing population $\hat{x}$ is greater than the level $\bar{x}/2$ of maximum sustained yield. It is this observation that seems to have led to the belief that a

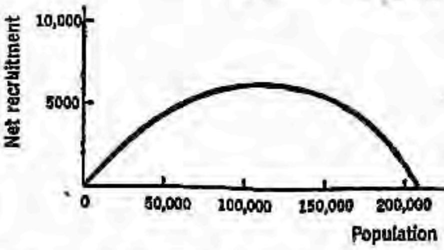


Fig. 1. Recruitment curve for blue whale population.

private resource owner would necessarily attempt to conserve his resource stock. I return to this question after discussing the common-property problem.

Since maximizing rent appears to be the same thing as maximizing profits, the question now arises, why in practice do fisheries and other resource industries never seem to attain this result? Economists have studied this question in detail; their solution was described by Gordon (8):

> In sea fisheries the natural resource is not private property; hence the rent it may yield is not capable of being appropriated by anyone. The individual fisherman is more or less free to fish wherever he pleases. The result is a pattern of competition among fishermen which culminates in the dissipation of the rent . . .

To summarize the argument for dissipation of rent, suppose first (see Fig. 3) that the fishery is actually operating at the rent-maximizing level $\hat{x}$. Then, observing that the working fishermen are making a profit, new fishermen will be attracted to the industry. Fishing intensity will increase and the fish population will decrease, as will the total rent. As long as any rent remains, the process continues. The fishery will expand until in the end the population reaches the level x_0 of zero economic rent. Thus, in a competitive situation, the rent will be entirely dissipated and economic efficiency will vanish.

In practice, fishermen will no longer be attracted to a fishery when they can earn a greater income in some alternative employment. This alternative income determines what economists call the opportunity costs of labor in fishing, and these costs are normally included in the total cost function. In cases of high unemployment, opportunity costs for fishermen may be nearly zero, so that the rent dissipation argument would be particularly forceful in explaining the overexploitation of fisheries.

So runs the standard economic argument for the overexploitation of resources, neatly laying the blame on open competition, particularly among the impoverished and the powerless. Yet the most spectacular and threatening developments of today, such as the reduction of the whale stocks and of the demersal fisheries on the Grand Banks, can by no means be attributed to impoverished local fishermen. On the contrary, it is the large, high-powered ships and the factory fleets of the wealthiest nations that are now the real danger. Poor and wealthy nations alike, however, may suffer unless successful control is soon achieved.

Economists themselves have begun to question the adequacy of the rent-dissipation argument to explain current developments (13). The fact that (as in the above model) extinction is theoretically impossible has been called "one of the more serious deficiencies of the received doctrine" (14). But the principal shortcoming of the existing theories is their disregard of the time variable, both biologically and economically.

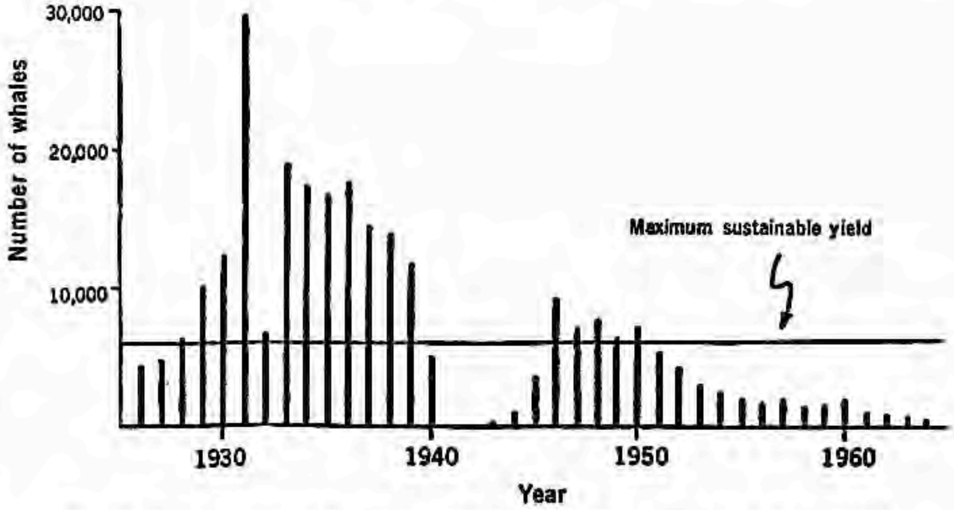
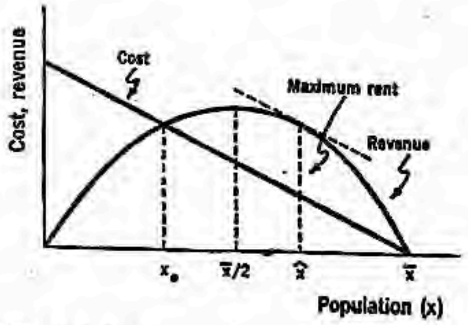


Fig. 2. Annual blue whale catch, 1925 to 1965. [Data compiled from (12)]



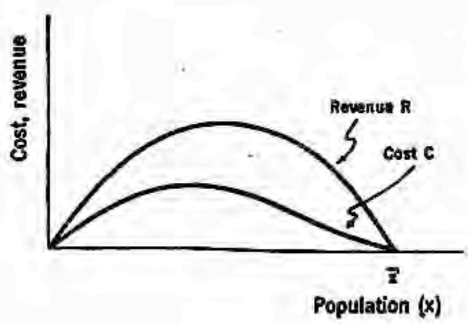


Fig. 3 (left). Economic rent. Fig. 4 (right). Cost-revenue curves (extinction feasible).

On the one hand, biological populations take time to respond to harvesting pressures, and only approach a new equilibrium after several seasons. On the other hand, but equally important, the value of monetary payments also possesses a time component due to the discounting of future payments. It denies the fundamental principles of economics itself to overlook the latter effect, and that is just what the rule of maximizing economic rent does.

The fact that maximization of rent and maximization of present value are not equivalent has long been recognized in agriculture (*15*) and forestry (*16*), and some analyses of fishing have also recognized the difference (*17*). The latter, however, have invariably utilized advanced mathematical techniques from the calculus of variations and optimal control theory, and are consequently somewhat beyond the level of intuitive understanding.

In the remainder of this article, I first show how the possibility of extinction can easily be included in the analysis, and then discuss the question of maximization of present value in resource management. The principal outcome will be that if extinction is economically feasible, then it will tend to result not only from common-property exploitation, but also from the maximization of present value, whenever a sufficiently high rate of discount is used (*18*). Generally, high rates of discount have the effect of causing biological overexploitation whenever it is commercially feasible.

The question of the cause of high discount rates is a complex one; it is sufficient to remark that at any time the discount rate adopted by exploiters will be related to the marginal opportunity cost of capital in alternative investments. In a technologically expanding economy, this rate could be quite large.

When applied to the Antarctic blue whale, the analysis indicates that an annual discount rate between 10 and 20 percent would be sufficient for extinction to result from maximization of the present value of harvests, assuming that extinction is commercially feasible. Such rates are by no means exceptional in resource development industries.

The question of the feasibility of extermination of the whale stocks is an interesting one. Gulland (*19*) has pointed out to me that fishing for the Antarctic blue whale probably would have become uneconomical several years earlier had it not been for the simultaneous occurrence of finback whales in the same area. It appears likely that the whalers agreed to a moratorium on blue whales in 1965 because they did not anticipate any significant further profits from the species.

These considerations raise serious doubts, in my opinion, about the wisdom of assuming that corporate resource exploiters will automatically behave in a socially desirable manner (*20*). There is no reason to suppose that the fishing corporations themselves desire regulations designed to conserve the world's fisheries. The governments of the world will fail in their responsibility to their citizens unless they succeed in formulating effective international conservation treaties in spite of pressures from these corporations.

Possibility of Extinction

The fact that populations can be driven to extinction by commercial hunting hardly needs to be emphasized. Only a minor change in the model described above is required in order to include the possibility of extinction in a reasonable way.

In Eq. 2 we made the assumption that harvesting costs vary inversely with population x. It thus appears that costs become infinite as x approaches zero. The variable x, however, is in reality restricted to integral values ($x = 1, 2, 3, \ldots$), and the cost of extinction is actually the cost of a unit harvest when $x = 1$. The simplest way to adjust the model to admit the possibility of extinction is to replace Eq. 2 by

$$C = \frac{By}{x+1} = \frac{ABx(\bar{x}-x)}{x+1} \qquad (2')$$

In this formula, the coefficient B represents the cost of extinction, that is, the cost of a unit harvest which reduces the breeding population from one to zero. If B is less than the price p, then the cost curve C will lie below the revenue curve $R = pAx(\bar{x}-x)$ for all values of x, as in Fig. 4. In this case the zero rent population x_0 equals zero, and rent dissipation will lead to extinction.

In practice, extinction may not require the actual extermination of the last member of the population. Biologists speak of a minimum viable population such that survival is impossible, or highly improbable, once the population falls below this level (*21*). Such a possibility is easily included in our model by replacing Eq. 1 for the net recruitment by

$$y = A(x - \underline{x})\,(\bar{x} - x) \qquad (1')$$

where $\underline{x}$ represents the minimal viable population. Note that there is no sustainable yield when $x < \underline{x}$. In this case extinction is again economically feasible provided the cost coefficient B of Eq. 2 or 2′ is small (*22*).

Henceforth for the sake of definiteness I adopt the model described by Eqs. 1 and 2′, so that extinction is feasible if the extinction cost B is less than the price p. (The more general case of Eq. 1′ can be treated by a similar analysis, or can be reduced to the previous case by shifting the origin of the population axis to the point $\underline{x}$ below which extinction becomes automatic.) Hence the rent function $R - C$ is given by

$$F(x) = pAx(\bar{x}-x) - \frac{ABx(\bar{x}-x)}{x+1} = f(x)\left[p - \frac{B}{x+1}\right] \qquad (3)$$

Maximization of Present Value

The concept of economic rent as discussed so far is time-independent. A more general understanding of th concept, as it applies to agricultural land economics, has been given by Gaffney (*15*), who identifies several categories of economic rent. Some of these do not apply to the case of fisheries or other wild animal resources, but his categories of conservable flow and expendable surplus are relevant in general.

In Gaffney's words, the expendable surplus is "that portion of virgin fertility whose emplaced value is less than its liquidation value." In other words, the immediate profit obtained from expending this surplus exceeds the present value of revenues that could be obtained in perpetuity by conserving it. Conversely the conservable flow refers to that portion of fertility whose emplaced value is greater than its liquidation value.

The expendable surplus thus provides a temporary contribution to rent, and disappears once it is expended, leaving the conservable flow as the enduring rent. Obviously, the expendable surplus and the conservable flow are complementary quantities; how much of virgin fertility is assigned to each category depends critically, as we shall see, on the rate of discount utilized in computing present values.

In our own case, let $\hat{x}$ now denote the economically conservable breeding population. The problem is to determine the value of $\hat{x}$. The conservable flow equals the rent $F(\hat{x})$ from Eq. 5, and the emplaced value of this rent is just the present value of a (continuous) annuity $F(\hat{x})$, namely

$$P_1(\hat{x}) = \int_0^\infty F(\hat{x})\, e^{-\delta t} dt = \frac{1}{\delta}\, F(\hat{x}) \qquad (6)$$

where $\delta > 0$ is the adopted discount rate. A high discount rate corresponds to a low emplaced value, and vice versa.

To derive the value of the expendable surplus, suppose that the population is originally at its natural equilibrium level $\bar{x}$. The surplus is therefore $\bar{x} - \hat{x}$, and this can produce an immediate gross revenue of $p(\bar{x} - \hat{x})$, at a harvesting cost given by

$$\int_{\hat{x}}^{\bar{x}} C(x) dx$$

where, as in Eq. 2′, $C(x) = B/(x+1)$ is the unit harvest cost at the population level x. Thus, the value of the surplus is equal to

$$P_2(\hat{x}) = p(\bar{x} - \hat{x}) - B \log \frac{\bar{x}+1}{\hat{x}+1} \qquad (7)$$

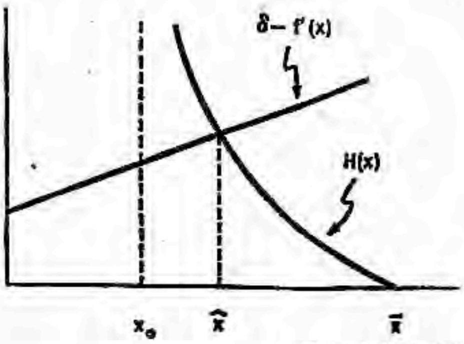


Fig. 5. Maximization of present value (extinction not feasible).

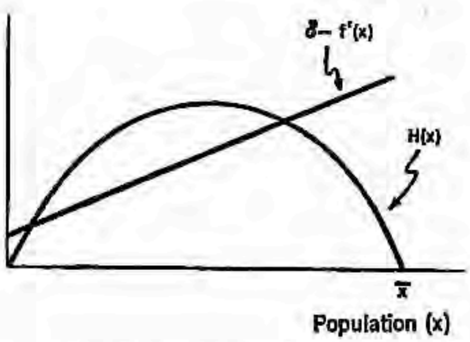


Fig. 6. Maximization of present value (extinction feasible).

The value of $\hat{x}$ is now determined by maximizing the total present value $P_1(\hat{x}) + P_2(\hat{x})$ (*23*). From Eqs. 6 and 7 we obtain, except in the end-point cases ($\hat{x} = 0$ or $\bar{x}$), the necessary condition

$$\frac{1}{\delta} F'(\hat{x}) = p - \frac{B}{\hat{x}+1} = p - C(\hat{x}) \qquad (8)$$

Equation 8 is a marginal condition of the type familiar in economic analysis. The right-hand expression, $p - C(\hat{x})$, represents the additional, or marginal, net revenue obtained by harvesting one unit from the population $\hat{x}$. The left-hand expression, $\delta^{-1}F'(\hat{x})$, is the marginal increase in the present value of the annuity $F(\hat{x})$ that results from leaving this additional unit of population to contribute to net recruitment. Neglecting exceptional cases, we must have equality of these marginal values at the optimal population $\hat{x}$.

Since by Eq. 5 we have $F(x) = f(x)[p - C(x)]$, a simple calculation reduces Eq. 8 to

$$\delta - f'(\hat{x}) = \frac{-C'(\hat{x})f(\hat{x})}{p - C(\hat{x})} \qquad (9)$$

[Equation 9 can be derived generally for an arbitrary recruitment function $f(x)$ and unit cost function $C(x)$.]

In analyzing Eq. 9 there are two cases to consider, depending on whether extinction is feasible or not. If $p < B = C(0)$, then extinction is not feasible. Let

$$p = C(x_0) \qquad (10)$$

so that x_0 represents the population at which price equals unit harvesting cost. Thus $F(x_0) = 0$, that is, x_0 is the "zero rent" level, which we found would be the level resulting from common-property dissipation of rent. Since $F(x) < 0$ for $x < x_0$, it is clear that the desired equilibrium population $\hat{x}$ must be $\geqslant x_0$.

Let $H(x)$ denote the expression on the right side of Eq. 9. Then (Fig. 5) $H(x) > 0$ for $x > x_0$ and the graph of $H(x)$ is asymptotic to the line $x = x_0$. The left side of Eq. 9 is a linear function with a positive slope. Consequently Eq. 9 has a solution $\hat{x}$ lying between x_0 and $\bar{x}$. The value $\hat{x}$ is the conservable population.

The two special cases $\delta = 0$ and $\delta = +\infty$ deserve comment. When $\delta = 0$, Eq. 8 implies that $F'(\hat{x}) = 0$. Thus, a zero discount rate corresponds to the maximization of economic rent and results in the largest possible conservable flow. When δ is infinite, on the other hand, we see from Fig. 5 that $\hat{x} = x_0$. In this case $F(\hat{x}) = 0$ and there is no conservable flow; the entire profitable portion of the virgin population is expendable surplus: it is completely dissipated. Rent maximization and rent dissipation thus occur mathematically as two extreme cases of maximization of present value.

Let us turn to the case $p > B$, in which extinction is feasible. In this case $H(x)$ is a positive bounded function (Fig. 6). Depending on the value of δ, there may be one, several, or no solutions to Eq. 9. As before, the case $\delta = 0$ corresponds to the maximization of rent. Now, however, the rent will be dissipated (and the population exterminated) not only for an infinite discount rate, but also for any sufficiently high rate. The following theorem is proved in the Appendix.

THEOREM. *Assume extinction is feasible ($p > B$). Then extinction will indeed occur as a result of the maximization of present value, whenever $\delta > 2f'(0)$.*

Note that $f'(0)$ represents the maximum reproductive potential of the population.

Let us return at last to the blue whales. Figure 1 indicates a maximum reproductive potential of about 10 percent per annum [and more recent reports indicate an even smaller rate, perhaps 4 to 5 percent (*11*)]. If in their calculations of profit and loss, the owners of the whaling fleets were to utilize an annual rate of discount of 20 percent or greater, they would therefore opt for complete extermination of the whales—at least as long as whaling remained profitable. This would occur whether they were competing, or cooperating, in the slaughter (*24*).

Summary

The general economic analysis of a biological resource presented in this article suggests that overexploitation in the physical sense of reduced productivity may result from not one, but two social conditions: common-property competitive exploitation on the one hand, and private-property maximization of profits on the other. For populations that are economically valuable but possess low reproductive capacities, either condition may lead even to the extinction of the population. In view of the likelihood of private firms adopting high rates of discount, the conservation of renewable resources would appear to require continual public surveillance and control of the physical yield and the condition of the stocks.

Appendix

To prove the theorem stated above, we will show that Eq. 9 has no solution in case $\delta > 2f'(0)$ and $p > B$; this implies that $\hat{x} = 0$ maximizes the total present value, since $\hat{x} = \bar{x}$ would give both zero rent and zero present value.

Since $H(x)$, the right-side expression in Eq. 9, is a decreasing function of p, it suffices to consider the case $p = B$. Then by the generalized mean value theorem of elementary calculus,

$$H(x) = -C'(x)\frac{f(x)}{C(0) - C(x)} = \frac{C'(x)f'(\xi)}{C'(\xi)} \quad (0 < \xi < x) < f'(\xi) < f'(0)$$

Thus $\delta - f'(x) > 2f'(0) - f'(x) > f'(0) > H(x)$, so Eq. 9 has no solution as claimed.

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$$\int \exp(-\delta t)\, h(t)\, \{p - C[x(t)]\}\, dt$$

for $h(t) \geq 0$ is equivalent to maximization o the simple expression $P_1(x) + P_2(x)$ describe here.
24. This possibility was also suggested by D. Fif [*Environment* **13** (No. 3), 20 (1971)].

25. Among the many friends and colleague whose ideas have contributed to this articl I would especially like to thank P. Bradley P. Pearse, A. Scott, and all other economist who have patiently suffered my errors.