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ECONOMIC DEPRECIATION, NATIONAL INCOME ACCOUNTING, AND COMMON PROPERTY RESOURCE MANAGEMENT

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I. Introduction

The alarming level of resource depletion and environmental degradation now occurring in developing countries has increased the sense of urgency among public officials and economists. As a consequence, the research agenda has moved beyond environmental impact assessments to comprehensive economic planning and policy design for effective management of natural resources and the environment (See e.g., Schramm and Warford [1989]). Two aspects of this recent literature are especially notable. The first is the emphasis on the resource systems approach to analysis, which applies systems engineering philosophy and methodology to investigate the complex interactions between government policy and large scale physical resource systems. This approach is being used to good effect in the study of problems related to forestry, water systems and soil management. The second is the attempt to incorporate measures of natural resource depletion in national income accounts. The motivation here is to measure true income net of depreciation as an indicator of sustainable development.

Significant progress has been made in both of these areas of investigation, but a rigorous conceptual foundation basis for measuring the economic depreciation of natural resources is wanting. A number of approaches to environmental and resource accounting have been suggested in the literature

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(see e.g., Ahmad, El Serafy and Lutz [1989], and Repetto [1989]). While these approaches are generally informative, they are limited in applicability. Properly interpreted, they either provide the basis for pragmatic approximation of resource depletion or they apply only in special cases. None is derived from a general model of resource depletion. In particular, most approaches are restricted to the case of exhaustible resources and are correct only when such resources are efficiently mined. Because of these theoretical limitations, producer royalty has typically been offered in policy discussions as the basis for regulating resource extraction (e.g., setting user fees) and for national income accounting. We contend that producer royalty is an inadequate measure for these purposes.

This paper presents a conceptual framework that we believe will serve as a sound basis for measuring the economic depreciation of natural resources. The framework we propose is founded on a theoretical model of resource depreciation which can be applied to the harvesting of renewable resources in both the steady state and in the transition to the steady state, as well as to the extraction of nonrenewable resources. Additionally, the model allows the planner to determine economic depreciation in the typical case that harvesting or extraction does not conform to an efficient program.

A related, but secondary, problem is the confusion that sometimes arises from ambiguities in the vocabulary of resource and development economics. Inconsistencies arising from imprecise terminology may contribute to misinterpretation and misapplication of economic theory in designing policy to achieve desired efficiency goals. For example, the World Bank and the Asian Development Bank advocate taxing the economic rents generated by resource harvesting (see e.g. Repetto [1989]). Such a policy can, in fact, be ineffective or even counterproductive. We suspect that semantic confusion may arise in part from an implicit presumption, underlying many resource policy discussions, that economic rent and economic depreciation are equivalent. We show below that the equivalency holds only when the resource is being efficiently managed, that is, when it is mined according to the competitive equilibrium extraction path. Inefficient management of a resource will generally produce economic rents (i.e., producer royalties) which differ significantly from the pure scarcity rent available from optimal harvesting. Taxing these rents can remove any incentives on the part of producers to switch to more efficient harvesting programs. We argue that a more appropriate policy would be to impose taxes on the estimated value of economic depreciation.

The plan of the paper is as follows. We first construct an optimal control model of resource extraction that integrates the cases of renewable and non-renewable resources. Using a simple example, we then contrast the difference between the optimum solution and the open access solution for resource use.

II. Efficient Depletion of a Renewable Resource

The theory of renewable resources is usually developed from the point of view of a price-taking resource owner. However, for purposes of supporting policy design and national income accounting, we construct a model of resource extraction from the point of view of a central planner maximizing total consumer-producer surplus.

Following the traditional approach (e.g., Hotelling [1931], and Scott and Munroe [1985]), we define the following variables:

$x(t)$: The stock of the resource.

$F(x)$: The natural growth function of the stock.

$h(t)$: The harvest rate.

$C(x)$: The unit cost of harvesting with Stock Size x.

$P(h)$: The demand schedule for the resource, which is assumed to be a downward sloping function of the harvest rate. (Here we are considering the market demand curve for the resources, rather than the demand curve for the output of a single producer.)

The efficient path can be found by maximizing W, the net present value of the resource to society:

$$W = \int_0^\infty \exp(-rt) \cdot \left(\int_0^{h(t)} P(q)dq \ - C[x(t)] \cdot h(t) \right) dt \tag{1}$$

Subject to the constraints

$$\dot{x} = F(x) - h(t) \text{ and } x(0) = \bar{x} \tag{2}$$

The present value Hamiltonian for this problem is

$$H = \exp(-rt) \cdot \left(\int_0^{h(t)} P(q)dq \ - C[x(t)] \cdot h(t) \right) - \lambda(t) \cdot [F(x) - h(t)] \tag{3}$$

where $\lambda(t)$ is the optimal control co-state variable.

Letting $\rho = P - C(x)$, necessary first-order conditions for an interior solution yield the key relationship:

$$\dot{P} + \frac{d[\rho F(x)]}{dx} = r\rho. \tag{4}$$

(See note 1 for details)

Equation (4) gives the optimal stock of the resources in each period and also determines, from equation (2), the optimal harvest path of the resource. The left and right sides of equation (4) can be interpreted as the marginal benefit and marginal cost respectively of increasing the stock size by one unit. The marginal benefit of withholding a unit off the market today consists of the capital gain that one can realize from selling that unit in the next period ($\dot{P}$) plus the increase in stock value due to the increase in growth of the the stock, $\frac{d[\rho F(x)]}{dx}$.

The marginal cost of withholding a unit of stock from the market is the foregone interest on the royalty from that unit, $r\rho$. Equation (4) can be combined with demand conditions to determine the intertemporal competitive equilibrium price path including the steady state, if it exists. For the typical renewable resource with a large initial stock, the optimal program will usually involve drawing the resource stock down during some interim period. During this transition period, competitive prices will be rising. Given a time invariant demand function, the resource may eventually be drawn down to a steady state level after which $\dot{P} = 0$. [Note that substituting $\dot{P} = 0$ into the equation (4) yields the "modified golden rule" of fisheries economics (see Munroe and Scott [1985]).

Rearranging equation (4) and dividing by r, we obtain the equivalent expression

$$\rho = \frac{1}{r}\dot{P} + \frac{1}{r}\left(\frac{d[\rho F(x)]}{dx}\right). \tag{5}$$

The first term on the right hand side of (5) is the opportunity cost of not having an asset a year hence which could have been sold for a capital gain of $\dot{P}$; the second term is the capitalized value of the royalty generated by the natural growth effect. Each of these terms represents an implicit cost of harvesting. In combination, they represent the user cost of harvesting an additional unit of the resource in the current time period. Here, we define user cost (following e.g., Scott [1953]) as the value of the opportunity lost when an alternative decision is implemented. In the context of resource extraction, user cost may be specified as the present value of future sacrifices associated with the current use of a marginal unit of the resource. By analogy to capital theory, user cost is economic depreciation, (see the appendix for a discussion of user cost and depreciation).

Equation (5) says that at the optimum solution, royalty equals economic depreciation. The royalty at the optimum is the scarcity rent - the rent that remains when competition has eroded all other rents. Scarcity rent arises because of foregone opportunities of using the resource in the future. That the term "scarcity rent" is used interchangeably with "royalty" and "user cost" in much of the resource economics literature helps to explain the common, but erroneous, conclusion that royalty is an appropriate measure of resource depreciation and a correct standard for efficiency-inducing user fees. In the approach suggested here, scarcity rent is defined only at the economic optimum. In contrast, economic depreciation has meaning regardless of whether or not harvesting follows the optimum trajectory; the marginal economic depreciation associated with the q_{th} unit of resource extracted is represented by the right hand side of equation (5), whether or not equality holds.

Note 1: The necessary first-order conditions for an interior solution to this problem are:

$$\frac{dx}{dt} = \frac{\partial H}{\partial \lambda} = F(x) - h(t) \tag{6a}$$

$$\frac{d\lambda}{dt} = \frac{-\partial H}{\partial x} = \exp(-rt) \cdot h(t) \cdot C'(x) - \lambda(t) \cdot F'(x) \tag{6b}$$

$$0 = \frac{\partial H}{\partial h} = \exp(-rt) \cdot \{P[h(t)] - C[x(t)]\} - \lambda(t) \tag{6c}$$

Solve (6c) for $\lambda(t)$, giving

$$\lambda(t) = \exp(-rt) \cdot \{P[h(t)] - C[x(t)\} \tag{7}$$

Substitute this into (6b).

$$\frac{d\lambda}{dt} = \exp(-rt) \cdot h(t) \cdot C'(x) - \exp(-rt) \cdot \{P[h(t)] - C[x(t)]\} \cdot F'(x) \tag{8}$$

Next, differentiate (7) with respect to time.

$$\frac{d\lambda}{dt} = -r \cdot \exp(-rt) \cdot [P - C(x)] + \exp(-rt) \cdot \left[\frac{dP}{dt} - C'(x) \cdot \frac{dx}{dt}\right] \tag{9}$$

Equate (8) and (9), cancel the exp(-rt) terms, and substitute the state equation (6a) for $\frac{dx}{dt}$ to yield:

$$-r \cdot [P - C(x)] + \frac{dP}{dt} - C'(x) \cdot [F(x) - h(t)] = h(t) \cdot C'(x) - [P - C(x)] \cdot F'(x) \tag{10}$$

$$\frac{dP}{dt} = r \cdot [P - C(x)] + C'(x) \cdot F(x) - [P - C(x)] \cdot F'(x) \tag{11}$$

Observe that the first term on the right hand side of (1) is r times the royalty, while the sum of the next two terms is the derivative of the expression F(x)[P - C(x)] with respect to x. Letting ρ represent the royalty, equation (12) reduces to equation (5).

Implication for Resource Management and Regulation

The treatment of scarcity rent and economic depreciation above has direct implications for policy in resource management. Organizations such a World Bank and Asian Development Bank have advocated government taxation of resource rents as a means of generating needed revenue and encouraging efficient use of natural resources (see Repetto [1989b]). Unfortunately, imprecise usage of the term rent has frequently led to policies which in fact, discourage efficient resource management. In particular, rent is typically interpreted by policy makers as current royalty or net return, which could actually exceed scarcity rent in the case of underharvesting of the resource. Taxing away this royalty removes managerial incentives to adjust the production of resource flow to the efficient level. At the other extreme, taxing of royalties less than scarcity rent, which is characteristic of overharvesting, provides no incentive for resource managers to cut back on harvesting and production. In both the under and overharvesting cases, the problem is that resource managers do not correctly incorporate economic depreciation in their harvesting and production decisions.

We suggest that a government leasing policy can be devised to accomplish two important policy objectives: (1) provide the proper incentives for resource managers to fully consider economic depreciation; and (2) extract the resource rents to which the government is entitled by virtue of public ownership of the resource. An effective government leasing policy that meets these objectives could be comprised of two policy instruments, a user fee and an auction.

The user fee is essentially a tax on the use of the resource and could be based either on economic depreciation or on scarcity rent. In either case, consideration of the marginal benefits and marginal costs of harvesting in each time period would induce the resource manager to adhere to an efficient harvesting program. The total amount assessed by the government during any time period would depend directly on the amount of resource harvested. Hence, extensive government monitoring of the operation would be required. If the user fee were based on economic depreciation, the tax per unit would vary with the amount harvested. In contrast, scarcity rent would form the basis for a fixed unit tax.

The other recommended component of an effective government leasing policy is an auction to allocate production licenses and property rights. The auction functions as the mechanism for capturing the resource rents the public is entitled to, but it serves other related objectives as well: (1) it reduces potential inequities within the private sector regarding the distribution of surpluses generated by the resource; (2) it eliminates inefficiencies created by rent-seeking behavior; and (3) it serves as a means for selecting the most capable resource managers.

To enforce compliance with the terms of the lease, the government could also require the resource manager to post a performance bond. The bond would be subject to forfeit if user fees were not properly paid or in the event of incomplete restoration of the production site following shutdown of the enterprise.

III. Applications to Open Access and Common Property Resource Management

It has been shown above that economic royalty (price minus extraction cost) is not an accurate measure of depreciation when the resource is being over or under exploited. This section deals with the possibility that common property resources may be over exploited, in which case, the shadow price of the resource (its user cost) will be less than economic royalty.

The popular notion that common property management is inevitably tragic is neither logically correct nor is it a correct interpretation of Hardin's (1968) classic article (see e.g., Roumasset [1991]). But while common property will not necessarily result in the open access steady state, it is not necessarily equivalent to sole ownership either. Indeed, since the temptations that Hardin and others have described are still present in common property management and are held only partially in check by constitutional restraints, common property management must be intermediate between open access and sole ownership. Social investments in the governance structures to impede over use will be made only up to the point that their marginal benefits equal their marginal cost, not until marginal benefits equal zero (the sole ownership solution).

The observation that common property resources are being utilized in a "sustainable" way, i.e. that the resource stock is being held constant, does not imply efficiency. Indeed, a centerpiece of the economics of fisheries is that the resource can be sustained at any stock level that generates a positive stock growth simply by setting the harvest rate equal to stock growth. Clearly, common property resources may be held at a stock level that is too low, relative to the efficient solution.

Moreover, it is not necessarily efficient to avoid depleting resources. So long as the resource stock is above the efficient steady state level, further depletion is warranted.

What is needed, then, is a benchmark of efficiency and a methodology for comparing a particular institutional regime to that benchmark. In what follows, we illustrate such an approach for the case of open access vs. an efficiently managed fishery.

A convenient approach, consistent with the work of Schaefer (1957) and other authors is to incorporate the concept of fishing effort into the model. In the usual formulation, the harvest rate h is specified as

$$h = qEx \tag{12}$$

with E representing effort. The constant q is called the "catchability coefficient". The hypothesis behind this formulation is that the catch per unit of effort in proportional to the current level of fish stock; i.e., that

$$\frac{h}{qE} = x \tag{13}$$

(See Clark [1991]) for a derivation of this relationship).

We now make the usual assumption that the total cost of applying fishing effort is given by

$$TC = C \cdot E \tag{14}$$

where C is a constant. In terms of harvest rate h, total cost would then be computed as

$$TC = \frac{C}{qx} \cdot h \, . \tag{15}$$

Therefore, we can take unit harvesting cost C(x) to be specified as an inverse function of the stock x:

$$C(x) = \frac{C}{qx} \, . \tag{16}$$

To simplify the exposition, we take as the natural growth function for the fish population to be the logistic equation:

$$F(x) = gx \left(1 - \frac{x}{k} \right) \tag{17}$$

where g is known as the intrinsic growth rate, and k is usually called the environmental carrying capacity.

Consider now the efficiency condition (5) in the steady state where $\dot{P} = 0$.

$$\rho = \frac{1}{r} \left[\frac{d[\rho F(x)]}{dx} \right] \tag{18}$$

Expanding both sides of (18), we get the equivalent expression

$$P - C(x) = \frac{1}{r} \left\{ F'(x)[P - C(x)] - C'(x)F(x) \right\} . \tag{19}$$

Substituting for F(x) and C(x) and computing the associated derivatives, the efficiency condition (19) becomes

$$[P - \frac{C}{qx}] = \frac{1}{r}\left\{[gP - \frac{gC}{gk}] - \frac{2Pg}{k}x\right\}. \tag{20}$$

As in the basic model, the right hand side of (20) represents economic depreciation; it is the opportunity cost of harvesting an additional unit in the current time period.

Independent of the efficiency condition signified by the equality in expression (20), each side represents a schedule in its own right. In particular, we can express economic depreciation as a function of the stock x for the case $0 < r < \infty$:

$$D(x) = \frac{1}{r}\left\{[\, gP - \frac{gC}{gk}\,] - \frac{2Pg}{k}x\right\}. \tag{21}$$

Note that $D'(x) = \frac{-2Pg}{rk} < 0$, so that D is a strictly decreasing function of x in this model.

With this framework in place, we can now compare the efficient solution with the open access solution. The efficient steady state stock level x^* is computed by solving the efficiency condition (20) for x.

Computation involves solution of a quadratic equation and x^* is taken as the positive root

$$x^* = x^*(C, g, k, P, q, r) \tag{22}$$

For this simple example, it can readily be shown by comparative static analysis that x^* decreases monotonically as the interest rate r increases (see Clark [1991] for a graphical argument). Note that this result may not hold in more general models.

The open access solution is based on the theory by Gordon (1954). The theory predicts that in the open access situation, fishing effort E will expand until all economic rents are dissipated, that is until total revenue, TR equals total cost, TC.

In this model, total revenue is given by

$$TR = P \cdot h = P \cdot qEx. \tag{23}$$

The two conditions governing the open access solution are then

$$\dot{x} = F(x) - h(t) = 0 \tag{24}$$

$$TR - TC = 0$$

Making the appropriate substitution, we obtain two specific equations:

$$gx\left(1-\frac{x}{k}\right)-qEx=0 \tag{25}$$

$$PqEx-CE=0.$$

Solution of the system (25) yields the results

$$E^{\infty}=\frac{g}{q}\left(1-\frac{c}{Pqk}\right) \tag{26}$$

$$x^{\infty}=\frac{C}{Pq}$$

The notation symbol ∞ is significant. The stock level x^{∞} attained θ under open access conditions is the same as would be realized in the efficient program with an infinite discount rate. This can be seen by writing (20) as

$$r\left[P-\frac{C}{qx}\right]=\left\{\left[gP-\frac{gC}{qk}\right]-\frac{2Pgx}{k}\right\}. \tag{27}$$

For x in the range [0,k], the right hand side of (21) is bounded. Thus as $r \rightarrow \infty$, we must have $P-\frac{C}{qx}\rightarrow 0$ or $x=\frac{C}{qx}$. This is precisely the open access solution.

In the context of this simple model, we have the basic result that for $0 < r < \infty$,

$$x^{*} > x^{\infty}$$

and consequently,

$$D(x^{*}) < D(x^{\infty}).$$

The implication is clear. At the optimum, royalty equals economic depreciation; i.e., marginal benefit equals marginal cost. In the case of open access fishing, economic depreciation exceeds the royalty, which is now zero, unless the interest rate is infinite.

Not only does the open access regime reach a steady-state resource stock that is too low, the rate of exploitation is also inefficient. This results from the tendency, in a more general model, for costs to increase with harvest in the current period.

However, when biological resources such as fish and trees are near their carrying capacity, resource harvesting increases the growth rate of the biomass, thus providing an offsetting force to resource depletion. As a consequence, the inefficiency of open access is small at high levels of the resource stock and the optimal governance structure for common property management is likely to be fairly permissive. This suggests that as the resource stock is depleted, the extent of efficient governance increases. The efficient constitution of common property management will evolve from a regime resembling open access to one much akin to private property.

The shadow price of a renewable resource, as derived above, provides a measure of the marginal benefit of increased conservation. As the resource is depleted, this marginal benefit rises, thus justifying greater investment in governance. At high levels of stock, governance strictures may be directed primarily at harvesting technology (avoiding damage to young trees and throwing back small fish). Later on greater attention may be given to regulations that restrict the total quantity of harvest.

IV. Concluding Remarks

The optimal control model of resource extraction that we present in this paper is intended to remedy a current deficiency in resource economics - the need for a general model of economic depreciation that can be applied to both renewable and nonrenewable resources and that remains valid away from the competitive equilibrium extraction path. Equation (5) embodies the primary concept. The necessary condition for efficient extraction of a resource can be expressed as marginal benefit (producer royalty) equals marginal cost (economic depreciation). Along the competitive equilibrium extraction path, royalty and economic depreciation are both equal to scarcity rent. The general optimality condition has important implications for resource-augmented national income accounting and resource management: royalty and economic depreciation are not necessarily equivalent away from the competitive equilibrium extraction path, and neither is necessarily equal to scarcity rent. For example, if the resource has been depleted beyond the efficient stock, then the user cost is greater than the royalty and scarcity rent is between the two.

The distinction between royalty and economic depreciation has motivated a conceptual framework for measuring resource depreciation that has wider application than existing methods of computing resource depletion. We offer this concept of resource depreciation as the basis for incorporating resource use into the national income accounts. In the case of a renewable resource, the model we present shows that resource use can generate negative depreciation, which augments, rather than decreases, national income. This result highlights the need for an expanded program of empirical research in the area of national income accounting. First, existing procedures for computing depreciation of exhaustible resources (see e.g., Landefeld and Hines [1985] and Repetto [1989b]) should be extended to the case of renewable resources. Second, methods are needed for computing economic depreciation when the harvesting program is inefficient, that is, when there is overharvesting or underharvesting relative to the competitive equilibrium trajectory.

Our development also shows that the distinction between royalty and economic depreciation has practical significance for policy design in resource management to control overuse or underuse of a resource. In the case of open access and other instances of overuse, where royalty is less than economic depreciation, taxing the royalty does not provide adequate incentive for resource conservation. Conversely, in the case of underuse of the resource, royalty will generally exceed economic depreciation, which may, in fact, be negative. Taxing away royalty penalizes the producer, who now sees no incentive to increase production to the efficient level. Yet, from the perspective of a central planner, increased harvesting might increase national income. In forestry management, for example, growth enhancement might be achieved by accelerated harvesting of slow growing trees to make room for faster growing trees. The definition of economic depreciation provided here is also appropriate for shadow pricing resources in benefit-cost analysis of projects proposed as part of government leasing programs.

The resource shadow price (user cost) can also be used as the basis of a theory of efficient common property governance. As a resource is depleted, its shadow price will typically rise, thus providing higher marginal benefits of conservation and justifying greater investment in governance. Thus the efficient form of common property management will change from a low-cost and permissive governance structure that approximates open access to a high-cost but incentive compatible institutional structure that resembles private property.

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