ECONOMICS OF RENEWABLE NATURAL RESOURCES

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Summary

Renewable natural resources include those resources useful to human economies that exhibit growth, maintenance, and recovery from exploitation over an economic planning horizon. The economics of such resources has traditionally considered stocks of fish, forests, or freshwater, much like a banker would tally interest on cash deposits. From an economic point of view, the management of biomass, soil fertility or aquifer depth has been forced into a framework of discounted, marginal, zero profit valuation. Economic value has been discounted to account for a positive time preference. Only marginal value (that of the next unit) is considered relevant to market-based decisions. And all economic profits (including a normal return to factor inputs) should be driven to zero to maximize the sum of consumer and producer surplus at a social optimum.

This framework can aptly be described as dynamic optimization and expanded to include risk and uncertainty, a social (vs. private) rate of time preference, non-market values, and systems without bias toward equilibrium. However, the type of management recommendations stemming from this conception of renewable resource systems have tended to include policy instruments that seek to influence decisions at the margin, often ignoring the more complex, non-linear, unpredictable relationships between economy, society, and the environment, to the detriment of long-term sustainability goals. An alternative view of natural resource economics has emerged from a systems view. An interdisciplinary understanding of feedback loops, discontinuities, and episodic change results in contrasting management recommendations focused on managing system

parameters for resilience, rather than squeezing out the last ton, board-foot, or cubic meter of a natural resource.

1. Introduction

The principal economic question in the management of renewable natural resources has been: How much of a resource should be harvested during the present vs. future time periods? Time is typically considered over the horizon of a single representative manager or economic operation. For instance, in ocean fisheries the economic question has been how much to harvest this season and how much to leave in the sea as a source of future growth next season. For a commercial forest operation, the economic question has concerned the length of time between harvests that maximizes a forest owner's profits. Similar examples comparing discounted income flows could be considered for renewable water, soil, or animal resources.

The question of when and how much to harvest has been posed as a balancing act between current and future benefits and costs. To strike this balance, economists have used methods of dynamic optimization (i.e. the best allocation over time). A renewable resource problem is typically framed as a maximization of some single measure of net economic value over some future time horizon, subject to the natural dynamics of the harvested resource, an initial stock size, a target for the end of the planning horizon (or a limit in the case of an infinite-time horizon), a measure of time preference, and other relevant market, price, and technology constraints. Advances in the treatment of risk and uncertainty, measurement of social versus private time preference, capture of non-market amenities, and analysis of non-equilibrium behavior have further extended this paradigm of efficient allocation.

The goal of economic efficiency – where the marginal benefits of a particular time path equate to the marginal costs – has been nearly singular in most economic models of renewable resources. These traditional economic concepts for the management of manufactured capital have been applied to natural capital, creating a concern for only the flows from natural capital (i.e. materials and energy) rather than the maintenance of capital stocks (i.e. life-support systems, regenerative capacity). However this focus on flows has been criticized as shortsighted and akin to living off capital rather than income. In contrast, a more complex view of renewable resources has emerged from a natural science perspective with an expanded focus on the scale of impact and resilience of ecosystem services. Recognition of complex interdependence on natural capital instead focuses on the resilience of non-substitutable capital stocks necessary for long-term economic activity. This adaptive systems perspective argues for renewable resource management regimes designed around the control of system parameters within domains of stability rather than targets for marginal extraction. Admittedly, a parametric management approach can forgo un-recovered economic profits, whereas marginal management by definition will push a competitive resource industry to a zero economic profit condition. However, if market efficiency is not the only goal of a management plan, then the adaptive systems perspective can aid in avoiding collapse of complex natural systems.

This article will first outline the essential elements of the dynamic optimization tradition of renewable resource economics. A summary of the fundamental equation of renewable resources highlights the essence of an efficient, market-based approach to management. Examples from fisheries and forest management are included to demonstrate the type of decision rules reached in this framework. Next, the treatment of stochastic change in renewable resource systems is briefly summarized in an optimal control framework. Finally, the adaptive systems management perspective is outlined, with an example of lake management highlighted in contrast to the optimal control perspective. Concluding remarks are offered in reference to the current status of renewable natural resources around the world.

2. Dynamic Optimization

Let a renewable resource X at time period t be described by the following discrete-time, first order difference equation:

$$X_{t+1} - X_t = F(X_t) - Y_t \quad (1)$$

where $F(X_t)$ represents a net growth function (i.e. birth less mortality), and Y_t is the period t harvest. Each period's addition to the current stock is estimated as the difference between growth and harvest. If harvest consistently exceeds growth, then the renewable resource must be in decline. Similarly, if growth consistently exceeds harvest, then the renewable resource is expanding. The existence and stability of steady-states, where harvest exactly equals growth in each time period (Y=F(X) for all t), can also be found in this framework and is often the focus of analysis.
For many renewable resources, the growth function is typically specified as dependent on an intrinsic growth rate (r), a carrying capacity (K), and periods of increasing and decreasing marginal additions to stock. In resources such as forests, a period of negative growth can also be specified to account for the effects of aging and decay. A popular growth curve of analysts is the logistic form:

$$F(X_t) = rX_t(1 - X_t/K) \quad (2)$$

and is represented in Figure 1, with the parameters normalized at r = 1 and K = 1.

Harvest (Y_t) can be specified as the choice variable, or itself modeled as a production function subject to technology, effort, and market conditions. For example, in the fisheries literature, it is standard practice to estimate a catchability coefficient (q) to represent technology, and model production as dependent on stock (X_t) and effort (E_t) in a constant returns to scale Cobb-Douglas function:

$$Y_t = H(X_t, E_t) = qX_tE_t \quad (3)$$

Effort, in turn, can be modeled as a function of profitability:

$$E_{t+1} = E_t + \eta[pH(X_t, E_t) - cE_t] \quad (4)$$

where $\eta > 0$ represents the speed to which effort adjusts to profit, p captures the price per unit of harvest, and c equals the cost per unit effort.

The allocation decision in this framework is a balance (or marginal trade-off) between the net benefits of more Y_t in the current period or more X_{t+1} in the next period, the source of future growth and benefits. Larger future stocks can also have the added benefit of reducing future harvest costs.

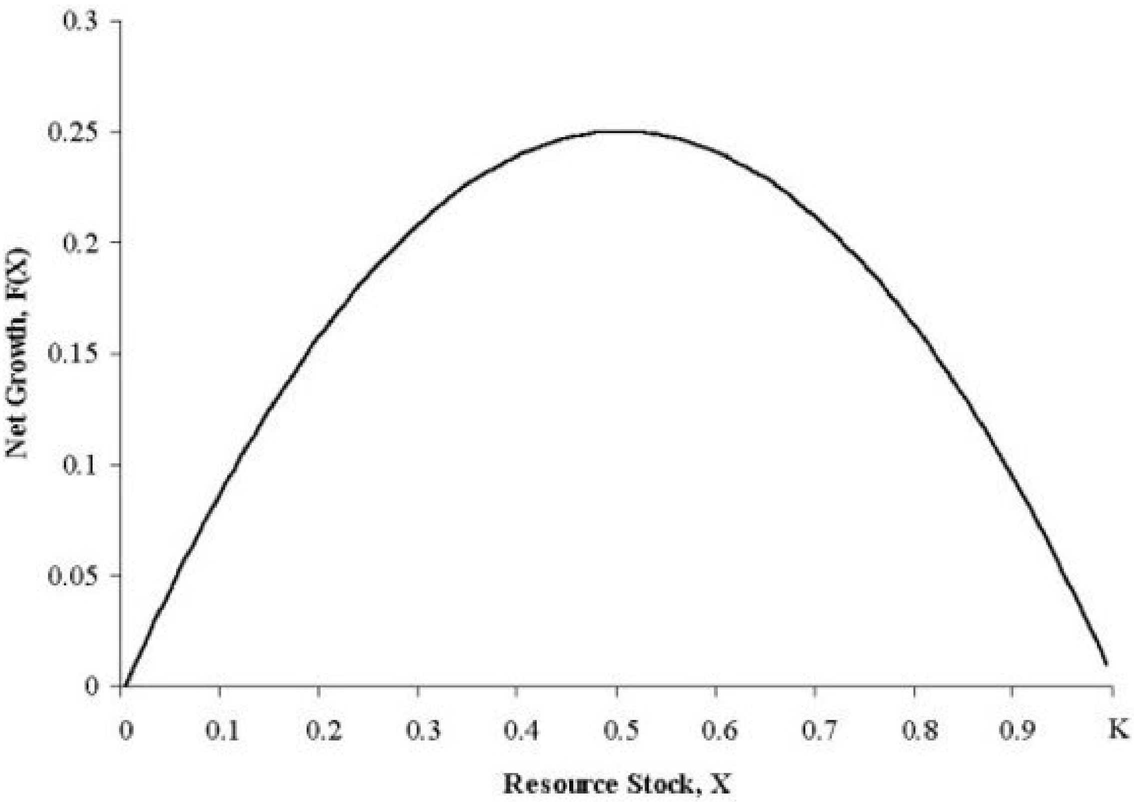

Figure 1: Theoretical Logistic Growth of a Renewable Resource

By specifying a net benefit function, Π(X, Y), and a discount rate, δ, methods of dynamic optimization can be used to estimate specific optimal time paths of effort, harvest, and resource stock. A number of methods exist for this purpose, with marginal valuation and discounting common to each.

2.1. Fundamental Equation of Renewable Resources

To illustrate the economic intuition characteristic of this class of resource allocation problems, consider the conditions for optimal management of a renewable resource in steady-state. Analytically, the time subscript can be dropped in order to solve for steady-state levels of X and Y. By specifying a net benefit function Π(X, Y) dependent on both steady-state stock size and harvest level, a discount rate (δ), and resource dynamics according to equation (1), the following two conditions must hold in an optimal steady-state:

$$Y = F(X) \tag{5}$$

$$F'(X) + \frac{\partial\Pi(X,Y)/\partial X}{\partial\Pi(X,Y)/\partial Y} = \delta \tag{6}$$

The first condition is obvious; harvest must equal growth at a steady-state point. The second condition, known in the literature as the fundamental equation of renewable resources, illustrates the economic logic common to classical resource economics. The left-hand side includes two terms. The first term, the total derivative of the growth function, captures the marginal addition to the net growth rate in the steady-state. The second term is the ratio of partial derivatives of the net benefit function with respect to stock in the numerator and harvest in the denominator. Known as the marginal stock effect, this term measures the marginal value of X relative to Y. Together, the left-hand side of equation (6) captures the internal rate of return of the resource at steady-state. At a steady-state optimum, equation (6) implies that this internal rate of return must be exactly equal to the opportunity cost of managing the resource (i.e. the discount rate).

The logic follows that an investor in a renewable resource will continue to harvest and draw down a resource stock so long as its internal rate of return is greater than what she could receive in return on her next best investment alternative. If this marginal return falls below what could be made by liquidating assets and investing in an alternative investment with a certain return of δ, then the investor should decrease harvest in the short-run and restore the equilibrium condition where marginal benefits equal marginal costs, or exit the industry in the long-run. Figure 1 represents a locus of points where $Y = F(X)$, ranging from $X = 0$ (extinction), $X = 0.5$ (maximum sustainable yield) to $X = K = 1$ (carrying capacity). With the condition implied by equation (6), a steady-state optimum can result in high ($X > 0.5$), low ($X < 0.5$), or extinct resource levels, depending on the various bioeconomic parameters specified. For instance, Colin Clark has used this framework to demonstrate that driving an animal species to extinction can be a market optimum.

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Biographical Sketch

Jon Erickson is an Assistant Professor in the Economics Department at Rensselaer Polytechnic Institute (Troy, New York, USA), where he teaches ecological economics, natural resource economics, regional economics, quantitative analysis, and introductory economics. He holds a B.S. in Applied Economics and Management, and M.S. and Ph.D. (1997) degrees in Natural Resource and Environmental Economics from Cornell University. Past positions include statistics lecturer at Cornell University, visiting lecturer at the University of Agriculture in Slovakia, consultant to Sandia National Laboratories, and a research specialist to the U.S. Agency for International Development. His current research interests include ecological-economic modeling, the dynamics of forest economies, land-use sustainability, and community geographical information system development. Other interests include renewable energy technology, regional development, and international energy and greenhouse gas policy. He has published in each of these areas, including recent papers in *Science*, *Ecological Economics*, and *Land Economics*. Jon has been a peer reviewer for the Intergovernmental Panel on Climate Change, the Environmental Protection Agency, the U.S. Department of Agriculture, the Hudson River Foundation, and numerous academic journals. His current research program supports Rensselaer's interdisciplinary Ph.D. program in Ecological Economics, including funded research on regional economic issues in the Adirondack Mountain and Hudson Valley regions of New York State. He is a founding member and the current president of the Adirondack Research Consortium, an organization created to foster and report research to inform policy-making and community planning in the region. In this capacity, he works to bridge the gap between information producers and users, cross disciplinary boundaries in the holistic study of a region, and integrate local knowledge and priorities into a community-driven research process. He is also active in the U.S. and International Societies for Ecological Economics.