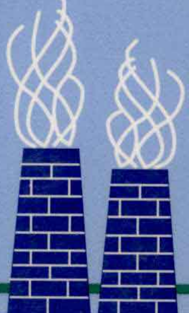
RESOURCE ECONOMICS

Jon M. Conrad



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Resource Economics

Resource Economics is a text for students with a background in calculus and intermediate microeconomics and a familiarity with the spreadsheet software Excel. The book covers basic concepts, shows how to set up spreadsheets to solve dynamic allocation problems, and presents economic models for fisheries, forestry, nonrenewable resources, stock pollutants, option value, and sustainable development. Within the text, numerical examples are posed and solved using Excel's Solver. These problems help make concepts operational, develop economic intuition, and serve as a bridge to the study of real-world problems of resource management.

Jon M. Conrad is Professor of Resource Economics at Cornell University. He taught at the University of Massachusetts, Amherst, from 1973 to 1977 before joining the Cornell faculty in 1978. His research interests focus on the use of dynamic optimization techniques to manage natural resources and environmental quality. He has published articles in *The Journal of Political Economy, The Quarterly Journal of Economics, The American Journal of Agricultural Economics, The Canadian Journal of Economics, Land Economics, Marine Resource Economics, Biomathematics, Ecological Economics*, and *The Journal of Environmental Economics and Management,* for which he served as an associate editor. He is the coauthor with Colin Clark of the text *Natural Resource Economics: Notes and Problems* (Cambridge University Press, 1987).

Preface

This book was written for students seeking an intermediate-level text in resource economics. It presumes that students have had differential calculus and intermediate microeconomics. It is designed to bridge the gap between texts which require only introductory economics and those which require graduate microeconomics and advanced methods of dynamic optimization such as the maximum principle and dynamic programming.

This text employs first-order difference equations to describe the change in a resource as it is harvested or extracted. Resource management is cast as a problem of optimal allocation over time, or dynamic optimization. The method of Lagrange multipliers is introduced to pose such problems conceptually and to examine the conditions that optimal management must satisfy. The unique and ideally appealing feature of this text is the use of Microsoft Excel Spreadsheet and Solver, a nonlinear programming algorithm within Excel, to solve numerical problems. Numerical problems help students see the dynamic trade-offs inherent in resource management and serve as a bridge from a general model to an empirical study of a real-world resource management problem. A familiarity with Excel is helpful but not essential. Chapter 2 introduces the student to Excel and shows how spreadsheets might be set up so that Solver can determine the optimal extraction of a nonrenewable resource or the optimal harvest of a renewable resource. By working through the examples in the text and the exercises at the end of each chapter the student will develop a feel and economic intuition for dynamic allocation problems along with an ability to solve and interpret numerical optimization problems.

The introductory chapter on basic concepts and Chapter 2 on solving numerical problems are followed by four chapters which develop economic models for the management of fisheries, forests, nonrenewable resources, and stock pollutants. Chapter 7 reviews the basic concepts in cost–benefit analysis on the way to a discussion of option value and the evaluation of decisions that are risky and irreversible. Chapter 8 explores the concept of sustainable development from several perspectives.

Following Chapter 8 is an annotated Bibliography of the topics covered in Chapters 1–8.

Policies which might improve the management of real-world resources are also examined. These policies include the use of individual transferable quotas in fisheries, the public acquisition of old-growth forest, emission taxes, and pollution permits. By working through the optimization problems first, the student will have a firm understanding of the role shadow prices play in optimal allocation. It is then easier to understand how policies which can introduce shadow prices into markets where they are absent are more likely to improve resource allocation than policies which ignore the motives and behavior of firms or individuals who harvest natural resources or generate residual wastes.

I would like to thank Jon Erickson and Chris Cole for their thorough reading of an earlier draft, checking the spreadsheets in the text and the answers to the numerical exercises at the end of each chapter.

Contents

CHAPTER 1

Basic Concepts

1.0 Renewable, Nonrenewable, and Environmental Resources

Economics might be defined as the study of how society allocates scarce resources. The field of resource economics would then be the study of how society allocates scarce natural resources such as stocks of fish, stands of trees, fresh water, oil, and other naturally occurring resources. A distinction is sometimes made between resource and environmental economics, where the latter field is concerned with the way wastes are disposed of and the resulting quality of air, water, and soil serving as waste receptors. In addition, environmental economics is concerned with the conservation of natural environments and biodiversity.

Natural resources are often categorized as being renewable or nonrenewable. A renewable resource must display a significant rate of growth or renewal on a relevant economic time scale. An economic time scale is a time interval for which planning and management are meaningful. The notion of an economic time scale can make the classification of natural resources a bit tricky. For example, how should we classify a stand of old-growth coast redwood or an aquifer with an insignificant rate of recharge? Whereas the redwood tree is a plant, and can be grown commercially, old-growth redwoods may be 800 to 1,000 years old, and their remaining stands might be more appropriately viewed as a nonrenewable resource. Whereas the water cycle provides precipitation that will replenish lakes and streams, the water contained in an aquifer with little or no recharge might be more economically similar to a pool of oil (a nonrenewable resource) than to a lake or reservoir that receives significant recharge from rain or melting snow.

A critical question in the allocation of natural resources is "How much of the resource should be harvested (extracted) today?" Finding the "best" allocation of natural resources over time can be regarded as a dynamic optimization problem. In such problems it is common to try to maximize some measure of net economic value, over some future horizon, subject to the dynamics of the harvested resource and any other relevant constraints. The solution to the dynamic optimization of a natural resource would be a schedule or "time path" indicating the optimal amount to be harvested (extracted) in each period. The optimal rate of harvest or extraction in a particular period may be zero. For example, if a fish stock has been historically mismanaged, and the current stock is below what is deemed optimal, then zero harvest (a moratorium on fishing) may be best until the stock recovers to a size at which a positive level of harvest is optimal.

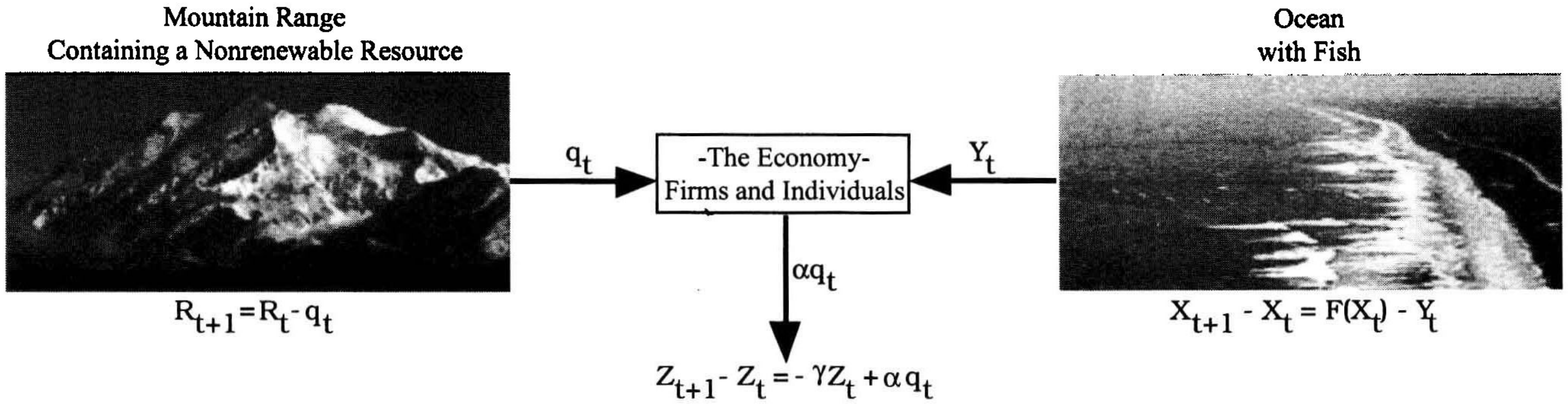
Aspects of natural resource allocation are depicted in Figure 1.1. On the right-hand side (RHS) of this figure we depict an ocean containing a stock of fish. The fish stock at the beginning of period t is denoted by the variable X_t, measured in metric tons. In each period the level of net growth depends on the size of the fish stock and is given by the function $F(X_t)$. We will postpone a detailed discussion of the properties of $F(X_t)$ until Chapter 3. For now, simply assume that if the fish stock is bounded by some "environmental carrying capacity," denoted K, so that $K \geq X_t \geq 0$, then $F(X_t)$ might be increasing as X_t goes from a low level to where $F(X_t)$ reaches a maximum sustainable yield (MSY) at X_{MSY}, and then $F(X_t)$ declines as X_t goes from X_{MSY} to K. Let Y_t denote the rate of harvest, also measured in metric tons, and assume that net growth occurs before harvest. Then, the change in the fish stock, going from period t to period $t + 1$, is the difference $X_{t+1} - X_t$ and is given by the difference equation

$$X_{t+1} - X_t = F(X_t) - Y_t \tag{1.1}$$

Note, if harvest exceeds net growth $[Y_t > F(X_t)]$, the fish stock declines $(X_{t+1} - X_t < 0)$, and if harvest is less than net growth $[Y_t < F(X_t)]$, the fish stock increases $(X_{t+1} - X_t > 0)$.

During period t, harvest, Y_t, flows to the economy, where it yields a net benefit to various firms and individuals. The stock left in the ocean forms the inventory at the beginning of the next period: i.e., X_{t+1}. This future stock also conveys a benefit to the economy, because it provides the basis for future growth, and it is often the case that larger stocks will lower the cost of future harvest. Thus, implicit in the harvest decision is a balancing of current net benefit from Y_t and future benefit that a slightly larger X_{t+1} would provide the economy.

On the left-hand side (LHS) of Figure 1.1 we show an equation describing the dynamics of a nonrenewable resource. The stock of extractable ore in period t is denoted by R_t and the current rate of extraction by q_t. With no growth or renewal the stock in period $t + 1$ is simply the stock in period t less the amount extracted in period t, so $R_{t+1} = R_t - q_t$. The amount extracted also flows into the economy, where it generates net benefits, but in contrast to harvest from the fish stock, consumption of the nonrenewable resource generates a residual waste, αq_t, propor-



Key

R_t = the stock of the nonrenewable resource in year t

q_t = the rate of production from nonrenewable resource in year t

αq_t = the flow of waste from q_t, $1 > \alpha > 0$

Z_t = the stock of accumulated waste

γZ_t = the rate of waste decomposition, $1 > \gamma > 0$

X_t = stock of fish in year t

Y_t = harvest of fish in year t

$F(X_t)$ = a net growth function

Figure 1.1. Renewable, Nonrenewable, and Environmental Resources

tional to the rate of extraction ($1 > \alpha > 0$). For example, if R_t were a deposit of coal (measured in metric tons) and q_t were the number of tons extracted and burned in period t, then αq_t might be the tons of CO_2 or SO_2 emerging from the smokestacks of utilities or foundries.

This residual waste can accumulate as a stock pollutant, denoted Z_t. If the rate at which the pollutant is generated, αq_t, exceeds the rate at which it is assimilated (or decomposed), $-\gamma Z_t$, the stock pollutant will increase, $(Z_{t+1} - Z_t > 0)$, whereas if the rate of generation is less than assimilation, then the stock will decrease. The parameter γ is called the assimilation or degradation coefficient, where $1 > \gamma > 0$. Not shown in Figure 1.1 are the consequences of different levels of Z_t. Presumably there would be some social or external cost imposed on the economy (society). This is sometimes represented through a damage function, $D(Z_t)$. Damage functions will be discussed in greater detail in Chapter 6.

If the economy is represented by the box in Figure 1.1, then the natural environment, surrounding the economy, can be thought of as providing a flow of renewable and nonrenewable resources, and also various media for the disposal of unwanted (negatively valued) wastes. Missing from Figure 1.1, however, is one additional service, usually referred to as *amenity value*. A wilderness, a pristine stretch of beach, or a lake with "swimmable" water quality provides individuals in the economy with places for observation of flora and fauna, relaxation, and recreation that are fundamentally different from comparable services provided at a city zoo, an exclusive beach hotel, or a backyard swimming pool. The amenity value provided by various natural environments may critically depend on the location and rate of resource extraction and waste disposal. Thus, the optimal rates of harvest, extraction, and disposal should take into account any reduction in amenity values. In general, current net benefit from, say, Y_t or q_t, must be balanced with the discounted future costs from reduced resource stocks, X_{t+1} and R_{t+1}, and any reduction in amenity values caused by harvest, extraction, or disposal of associated wastes.

1.1 Discounting

When attempting to determine the optimal allocation of natural resources over time one immediately confronts the issue of "time preference." Most individuals exhibit a preference for receiving benefits now, as opposed to receiving the same level of benefits at a later date. Such individuals are said to have a positive time preference. In order to induce these individuals to save (thus providing funds for investment), an interest payment or premium, over and above the amount borrowed, must be offered. A society composed of individuals with positive time preferences will typically develop "markets for loanable funds" (capital markets) where the interest rates which emerge are like prices and reflect, in part, society's underlying time preference.

An individual with a positive time preference will discount the value of a note or contract which promises to pay a fixed amount of money at some future date. For example, a bond which promises to pay \$10,000 10 years from now is not worth \$10,000 today in a society of individuals with positive time preferences. Suppose you own such a bond. What could you get for it if you wished to sell it today? The answer will depend on the credit rating (trustworthiness) of the government or corporation promising to make the payment, the expectation of inflation, and the taxes that would be paid on the interest income. Suppose the payment will be made with certainty, there is no expectation of inflation, and there is no tax on earned interest. Then, the bond payment would be discounted by a rate that would approximate society's "pure" rate of time preference. We will denote this rate by the symbol δ, and simply refer to it as the *discount rate*. The risk of default (nonpayment), the expectation of inflation, or the presence of taxes on earned interest would raise private market rates of interest above the discount rate. (Why?)

If the discount rate were 3%, so $\delta = 0.03$, then the "discount factor" is defined as $\rho = 1/(1 + \delta) = 1/(1 + 0.03) \approx 0.97$. The present value of a \$10,000 payment made 10 years from now would be $\$10{,}000/(1 + \delta)^{10} = \$10{,}000\rho^{10} \approx \$7{,}441$. This should be the amount of money you would get for your bond if you wished to sell it today. Note that the amount \$7,441 is also the amount you would need to invest at a rate of 3%, compounded annually, to have \$10,000 10 years from now.

The present-value calculation for a single payment can be generalized to a future stream of payments in a straightforward fashion. Let N_t denote a payment made in year t. Suppose these payments are made over the horizon $t = 0, 1, 2, \ldots, T$, where $t = 0$ is the current year (period) and $t = T$ is the last year (or terminal period). The present value of this stream of payments can be calculated by adding up the present value of each individual payment. We can represent this calculation mathematically as

$$N = \sum_{t=0}^{t=T} \rho^t N_t \tag{1.2}$$

Suppose that $N_0 = 0$ and $N_t = A$ for $t = 1, 2, \ldots, \infty$. In this case we have a bond which promises to pay A dollars every year, from next year until the end of time. Such a bond is called a perpetuity, and with $1 > \rho > 0$, when $\delta > 0$, equation (1.2) becomes an infinite geometric progression which converges to $N = A/\delta$. This special result might be used to approximate the value of certain long-lived projects or the decision to preserve a natural environment for all future generations. For example, if a proposed park were estimated to provide $A = \$10$ million in annual net benefits into the indefinite future, it would have a present value of \$500 million at $\delta = 0.02$.

The preceding examples presume that time can be partitioned into discrete periods (for example, years). In some resource allocation problems, it is useful to treat time as a continuous variable, where the future horizon becomes the interval $T \geq t \geq 0$. Recall the formula for compound interest. It says that if A dollars is put in the bank at interest rate δ, and compounded m times over a horizon of length T, then the value at the end of the horizon will be given by

$$V(T) = A(1+\delta/m)^{mT} = A\left[(1+\delta/m)^{m/\delta}\right]^{\delta T} = A\left[(1+1/n)^{n}\right]^{\delta T} \qquad (1.3)$$

where $n = m/\delta$. If interest is compounded continuously, both m and n tend to infinity and $[1 + 1/n]^n$ tends to e, the base of the natural logarithm. This implies $V(T) = A\ e^{\delta T}$. Note that $A = V(T)e^{-\delta T}$ becomes the present value of a promise to pay $V(T)$ at $t = T$ (from the perspective of $t = 0$). Thus, the continuous-time discount factor for a payment at instant t is $e^{-\delta t,}$ and the present value of a continuous stream of payments $N(t)$ is calculated as

$$N = \int_{0}^{T} N(t)e^{-\delta t}dt \qquad (1.4)$$

If $N(t) = A$ (a constant) and if $T \to \infty$, equation (1.4) can be integrated directly to yield $N = A/\delta$, which is interpreted as the present value of an asset which pays A dollars in each and every instant into the indefinite future.

Our discussion of discounting and present value has focused on the mathematics of making present-value calculations. The practice of discounting has an important ethical dimension, particularly with regard to the way resources are harvested over time, the evaluation of investments or policies to protect the environment, and more generally the way the current generation weights the welfare and options of future generations.

In financial markets the practice of discounting might be justified by society's positive time preference and by the economy's need to allocate scarce investment funds to firms which have expected returns that equal or exceed the appropriate rate of discount. To ignore the time preferences of individuals and to replace competitive capital markets by the decisions of some savings/investment czar would likely lead to inefficiencies, a reduction in the output and wealth generated by the economy, and the oppression of what many individuals regard as a fundamental economic right. The commodity prices and interest rates which emerge from competitive markets are highly efficient in allocating resources toward those economic activities which are demanded by the individuals with purchasing power.

Although the efficiency of competitive markets in determining the allocation of labor and capital is widely accepted, there remain questions about discounting and the appropriate rate of discount when allocating natural resources over time or investing in environmental quality. Basically the interest rates that emerge from capital markets reflect society's underlying rate of discount, the riskiness of a particular asset or portfolio, and the prospect of general inflation. These factors, as already noted, tend to raise market rates of interest above the discount rate.

Estimates of the discount rate in the United States have ranged between 2% and 5%. This rate will vary across cultures at a point in time and within a culture over time. A society's discount rate would in theory reflect its collective "sense of immediacy" and its general level of development. A society where time is of the essence or where a large fraction of the populace is on the brink of starvation would presumably have a higher rate of discount.

As we will see in subsequent chapters, higher discount rates tend to favor more rapid depletion of nonrenewable resources and lower stock levels for renewable resources. High discount rates can make investments to improve or protect environmental quality unattractive when compared to alternative investments in the private sector. High rates of discount will greatly reduce the value of harvesting decisions or investments that have a preponderance of their benefits in the distant future. Recall that a single payment of $10,000 in 10 years had a present value of $7,441 at $\delta = 0.03$. If the discount rate increases to $\delta = 0.10$, its present value drops to $3,855. If the payment of $10,000 would not be made until 100 years into the future, it would have a present value of only $520 at $\delta = 0.03$ and the minuscule value of $0.72 (72 cents) if $\delta = 0.10$.

The exponential nature of discounting has the effect of weighting near-term benefits much more heavily than benefits in the distant future. If 75 years were the life span of a single generation, and if that generation had absolute discretion over resource use and a discount rate of $\delta = 0.10$, then the weight attached to the welfare of the next generation would be similarly minuscule. Such a situation could lead the current generation to throw one long, extravagant, resource-depleting party that left subsequent generations with an impoverished inventory of natural resources, a polluted environment, and very few options to change their economic destiny.

There are some who would view the current mélange of resource and environmental problems as being precisely the result of tyrannical and selfish decisions by recent generations. Such a characterization would not be fair or accurate. Although many renewable resources have been mismanaged (such as marine fisheries and tropical rain forest), and various nonrenewable resources may have been depleted too rapidly (oil reserves in the United States), the process, though nonoptimal, has generated both physical and human capital in the form of buildings, a housing stock, highways and public infrastructure, modern agriculture, and the advancement of science and technology. These also benefit and have expanded the choices open to future generations. Further, any single generation is usually closely "linked" to the two generations which preceded it and the two generations which will follow. The current generation has historically made sacrifices in their immediate well-being to provide for parents, children, and grandchildren. Although intergenerational altruism may not be obvious in the functioning of financial markets, it is more obvious in the way we have collectively tried to regulate the use of natural resources and the quality of the environment. Our policies have not always been effective, but their motivation seems to derive from a sincere concern for future generations.

Determining the "best" endowment of human and natural capital to leave future generations is made difficult because we do not know what they will need or want. Some recommend that if we err, we should err on the side of leaving more natural resources and undisturbed natural environments. By saving them now we derive certain amenity benefits and preserve the options to harvest or develop in the future.

The process of discounting, to the extent that it reflects a stable time preference across a succession of generations is probably appropriate when managing natural resources and environmental quality for the maximum benefit of an ongoing society. Improving the well-being of the current generation is a part of an ongoing process seeking to improve the human condition. And when measured in terms of infant mortality, caloric intake, and life expectancy, successive generations have been made better off.

Nothing in the preceeding discussion helps us in determining the precise rate of discount which should be used for a particular natural resource or environmental project. In the analysis in future chapters we will explore the sensitivity of harvest and extraction rates, forest rotations, and rates of waste disposal to different rates of discount. This will enable us to get a numerical feel for the significance of discounting.