Economics and the Easter Island Metaphor

*Thomas R. Dalton, R. Morris Coats, and Leon Taylor**

FOLLOWING THE PUBLICATION of Brander and Taylor's 1998 paper, "The simple economics of Easter Island: A Ricardo-Malthus model of renewable resource use," in the *American Economic Review,* resource economists have been interested in further developing a model to show how conflict, human institutions and customs, and technological change might act and interact to exacerbate or ameliorate the feast-famine or predator-prey cycle that caused catastrophe on Easter Island (Rapa Nui). The island is seen as a useful metaphor for the interaction of humans with their natural environment and danger that the planet will collapse. Indeed, Malthus, following the voyages of Captain James Cook, saw islands and the population problems that islanders face as metaphors for the earth's population problems.

> Though the barriers to a further increase of population be not so well defined, and so open to common observation, on continents as on islands, yet they still present obstacles that are nearly as insurmountable; and the emigrant, impatient of the distresses which he feels in his own country, is by no means secure of finding relief in another. There is probably no island yet known, the produce of which could not be further increased. This is all that can be said of the whole earth.... The question that is asked in Captain Cook's first Voyage, with respect to the thinly scattered savages of New Holland, "By what means the inhabitants of this country are reduced to such a number as it can subsist?" may be asked with equal propriety respecting the most populous islands in the South Sea, or the best peopled countries in Europe and Asia. The question, applied generally, appears to me to be highly curious, and to lead to the elucidation of some of the most obscure, yet important points, in the history of human society.
>
> Reverend Thomas Robert Malthus
> (Ch. V in paragraph I.V.1,1826)

INTRODUCTION

THE SETTLEMENT OF THE FAR-FLUNG ISLANDS of the Pacific is one of the great achievements of pre-industrial civilization. The variety of island types, including small volcanic masses and coral atolls as well as larger and more verdant islands, and their wide dispersal across the Pacific – from tropical to temperate climatic zones – presented small colonizing groups with significant adaptive challenges and provided numerous opportunities for experiments in human adaptation in isolated environments (Barthel 1978; Finney et al. 1989).

More than a dozen marginally habitable islands have archaeological records of prehistoric settlement for varying periods of time. All of these societies had declined and virtually disappeared before the arrival of Europeans in the 18th century. The sophistication and stability of these early colonies as well as their disappearance has prompted an extensive amount of research to reveal the mechanisms by which they prospered and failed (Bender et al. 2002; Kirch 1986; Mulloy 1979). Research has been multi-disciplinary, including contributions from archaeology, biology and, recently, economics. This article summarizes economic research that uses mathematical simulation to examine various features of the growth and decay of insular populations, emphasizing the experience on Easter Island.

Easter Island is well known, primarily for its *moai*, but the population pattern that emerges there is typical: an initial period of sustained prosperity,[1] followed by rapid decline with falling welfare as the resource base of the island was depleted. This pattern suggests that unregulated resource exploitation caused a feast and famine cycle that overtaxed the capacity of the resource base and eventually led to the collapse of the society.

Malthus is probably the most famous of the early modern thinkers to address the population problem, noting that human population and the natural ecological system were on a collision course because, according to Malthus, the exponential growth of populations would exceed the linear growth in agricultural advances and thus outstrip our abilities to feed ourselves: food supply limitations lead to population limitations. He notes that the system will have several possible solutions or resolutions (several possible steady-state equilibria) to limit population growth, such as famine, war, disease, in-

*T. R. Dalton, Professor of Economics, University of Arizona, Tucson, AZ 85721; R. Morris Coats, Argent Bank Professor of Economics, Nicholls State University, Thibodaux, LA 70310; Morris.Coats@nicholls.edu, corresponding author; Leon Taylor, Associate Professor of Economics, KIMEP, The Kazakhstan Institute of Management, Economics, and Strategic Research, Almaty, Kazakhstan

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[1] Polynesian settlement of Easter Island probably began somewhere around the 9th century, though one site, the so-called *Poike* ditch, has charcoal dated from 320-670 A.D. as discussed in Martinsson-Wallin and Crockford (2001) who give a range for the earliest settlement from the 7th to the 11th century. The period of prosperity lasted until the 14th century. The single *Poike* ditch sample is discounted because the earliest settlers surely had access to an ample supply of driftwood for fuel. Dates coming from trees that could have been dead for centuries before being used for fuel make carbon dating of settlement difficult.

sufficient nutrition for children, and other natural limits to population.[2] In later editions of his book, Malthus also mentions that various social institutions to reduce births, such as late marriages, social sanctions against early motherhood, and sterilization could lead to a more stable population.[3]

Malthus thus sees institutions as a check on population growth and a way around the social collapse that his theory predicts. Hardin (1968), Gordon (1954), and Coase (1960) have pointed out the particular role of property-rights institutions and/or the costs of transacting in over-grazing, overfishing, and over-hunting, as well as in all other pollution problems. Economists have also analyzed the unsustainable use of natural resources as a problem due to common-property institutions. They believe that private property-rights regimes can induce users to consider the cost of their actions in terms of lost reproduction of the natural resource. For instance, the American bison were wastefully slaughtered, while cattle were slaughtered in far greater numbers, but at sustainable rates, with great market value placed on bulls, because one bull could sire many calves per year. The reproductive stock was important capital to be guarded and kept in good health. Bison could only be owned by slaughtering them, so that the only "good (market-valued) bison was a dead bison." More recently, Ostrom (1990) suggests that the problem of over-exploitation is due more specifically to open-access common property rights regimes and that there are common property regimes where access is limited somehow, which we often see among indigenous peoples in traditional societies.

All of the work done in this literature builds upon the work of Brander and Taylor (1998). In our review of the economics literature on Easter Island, we first present the economic model proposed in their seminal work, which simulated the Malthusian history of Easter Island's feast-famine or predator-prey cycles of people and resource base. Then we turn to modifications of the Brander and Taylor model that examine the three influences of institutions, technological growth, and war, as well as the interplay of these influences. Finally, we examine some recent work done outside of economics on Easter Island by Diamond (2005) and Rolett and Diamond (2004).

Simulation of Growth and Decline on Easter Island

Brander and Taylor (1998) initiated the current economic interest in the somewhat isolated development of Easter Island by constructing a simulated model of its prehistoric economy, based on biological and cultural parameters that closely approximate conditions that researchers believe existed at its founding. Brander and Taylor (B&T) develop a simple model of the Easter Island economy, using parameters from Bahn and Flenley's (1992) review of the archaeological research of Easter Island.[4] Brander and Taylor employ a Lotka (1925) – Volterra (1931) predator-prey dynamic model based on Schaefer's model of resource dynamics and Malthusian model of human population dynamics, such that the growth rate in the human population depends on the resource stock and on the harvest of that stock. This "economic" model of the island does not presuppose modern economic institutions, such as money, but rather examines the changes in human consumption choices when faced with changing production capabilities, given the sorts of trading or sharing arrangements we might surmise existed on prehistoric Easter Island.

The Brander and Taylor (1998) model has two main interacting functions: a resource stock function which depends both on its natural rate of growth as well as on the rate at which the resource is harvested, and a population stock function which also depends on the amount of the resource harvested. The resource stock at time t is S(t). The growth rate of the resource stock is equal to the natural growth rate of the resource, G(S(t)) minus the harvest rate, H(t), so that

$$dS/dt = G(S) - H \text{ (sans time argument t). (1)}$$

The logistic form of G, borrowed from Schaefer (1957), is

$$G(S) = rS(1-S/K), \quad (2)$$

where K is the carrying capacity, or the maximum size of the resource stock, and r is the intrinsic growth rate of the resource, its regeneration rate.

The rate of harvesting, H, is both based on a constant fraction of the resource stock and the population of workers used in harvesting, L_H (simplifying by assuming that the entire population works, but this assumption is not necessary to their story):

$$H = \alpha S L_H, \quad (3)$$

where α is a constant between 0 and 1. Whatever labor that is not used to harvest the resource is used in manufacturing a good that we will just call M, a composite good of tools, housing, *moai* construction and so forth. The labor devoted to manufacturing is denoted, L_M. The total labor supply, or simply the population, is denoted as L. Thus, $L = L_H + L_M$.

Since we can choose units, we can define one unit of M as the amount produced by one unit of labor, so that the wage,

[2] "The positive checks to population are extremely various, and include every cause, whether arising from vice or misery, which in any degree contributes to shorten the natural duration of human life. Under this head, therefore, may be enumerated all unwholesome occupations, severe labour and exposure to the seasons, extreme poverty, bad nursing of children, great towns, excesses of all kinds, the whole train of common diseases and epidemics, wars, plague, and famine." Malthus 6th ed 1826, paragraph I.II.9.

[3] Malthus 6th ed 1826, Chapter V in paragraph I.V.1

[4] It should be noted that the Bahn and Flenley's (1992) interpretation of Easter's prehistory and particularly its collapse is not as accepted today as it was when Brander and Taylor published their work. See, for example, Rainbird 2001.

w,[5] must equal 1. Prices are defined in terms of the manufactured good, M (which is a numeraire good, the price of which is normalized to 1).

Both manufacturing and harvesting occur under conditions of free entry. Since there is open access to the harvesting, there is no rental cost[6] or user cost for the resource S. The only cost of the resource is the cost of harvesting it. The price of a resource or harvested good is p, which must equal its unit cost of production because of the free entry condition, or open access, so that $p = w/\alpha S$, or $p = 1/\alpha S$.

B&T employ a general and flexible instantaneous utility function termed a Cobb-Douglas utility function to provide preferences, so that utility, u, is

$$u = h^{\beta}m^{1-\beta} \qquad (4)$$

where h and m represent the individual level of consumption of the resource and the manufactured good, respectively and β is a parameter of the utility function, a constant between 0 and 1. The utility function is maximized subject to the instantaneous budget constraint, $ph + m = w$, yielding optimal amounts of h and m consumed per worker:

$$h = w\beta/p \text{ and} \qquad (5)$$

$$m = w(1-\beta). \qquad (6)$$

Total demand is simply L times the individual demand, so that

$$H = w\beta L/p \text{ and} \qquad (7)$$

$$M = w(1-\beta)L. \qquad (8)$$

At any moment t, the resource is fixed at S(t), and the population is fixed at L(t). Using all labor, the temporary equilibrium is at $w = 1$, such that

$$H = \alpha\beta LS \text{ and} \qquad (9)$$

$$M = (1-\beta)L. \qquad (10)$$

The equilibrium harvest rate may exceed the biological growth rate G, so that the resource stock may shrink. Substituting our (temporary) equilibrium harvest (9) from biological growth (2) into the change in the renewable resource equation (1), yields

$$dS/dt = rS(1-S/K) - \alpha\beta LS. \qquad (11)$$

If the stock of the resource falls, the productivity of labor in the resource sector of the economy falls and the productive ability of the economy is reduced.

Fertility in the B&T model depends on per capita resource consumption, so that population growth, dS/dt, is based on the current population, L; on underlying birth and death rates, denoted as b and d, respectively; and on a fertility function, F, that is based on a positive constant, φ, of the per capita consumption of the resource good, H/L. From (9) we see that $H/L = \alpha\beta S$, then

$$dS/dt = L(b - d + \varphi\alpha\beta S) \qquad (12)$$

Brander and Taylor (1998) note that equations (11) and (12) form a two-equation system of differential equations, a variation of the Lotka-Volterra predator-prey model. Brander and Taylor used the parameters in Table 1. First, the time-period is set at a decade. The carrying capacity parameter, K, is largely chosen for convenience, so that the resource stock and the population will be similar in size. The fertility parameter, φ, is set at 4, so that as long as the resource stock satisfies $S \geq .5K$ (half the carrying capacity of the island) the population grows. If the stock is less than .5K, the population declines. The net population growth when the resource stock is driven to extinction is -.1, declining 10 percent per decade. The parameter β shows the relative preference for the resource good and the share of the labor force devoted to harvesting the resource. B&T suggest that there is evidence that somewhat less than half of the work of Easter Islanders was devoted to harvesting, so that 0.4 is in a reasonable range. Setting $\alpha = .00001$ would let a household harvest enough so that it could reproduce itself with just 20 percent of its labor time if the resource stock were at carrying capacity. The value of r is based on what is known about the reproduction of palms with Easter Island's soil and climate.[7] According to Dransfield et al (1984) the palm forest on Easter Island was a species of *Jubaea Chilensis*, which grows nowhere else in Polynesia and may be the only palm that can survive in Easter Island's cooler climate.

[5] Note that because we are dealing with a mostly prehistoric society and there is no evidence that money was used, wages in this literature refer to the goods the average worker receives as his share of the output, in terms of the amount of the manufactured goods for which his output could be traded.

[6] Again, since there are no monetary units here, rental and user costs do not refer to monetary costs. The term "user cost" refers to costs of using the resource now over and above harvesting or extraction costs. These costs are due to losses in future value of the resource from using it today and making it less available in the future. "User cost," then is a cost due to people's awareness of the resource's future scarcity, not just its current scarcity.

[7] While we use the palm resource in our discussions, following Brander and Taylor (1998), we recognize that the palm forest was not directly a food resource. However, the palm was a critical resource as wood for cooking and for protecting the soil. Diamond (2005:104) mentions 21 other known species of trees that had once been on Easter Island, but became extinct. Among these were hardwoods that were known to be used for canoes elsewhere in Polynesia. Canoes were vital for off-shore fishing. Brander and Taylor (1998:122) suggest that the loss of the forests around 1400 led to less protein in diets and that the reduction in forest cover led to reduced water retention in the soil, and soil erosion. Additionally, we can think of this instead as a generic renewable resource that can be depleted through harvesting at rates faster than the growth of the resource, for instance, the overexploitation of birds on the island, as Anderson (2002) discusses.

B&T also use 40 as the initial value for the population, L, in AD 400, when Polynesians were first thought to arrive on Easter Island and 12,000 (carrying capacity, K) as the initial value for S.[9] A simulation of Easter Island's economy, based on equations (11) and (12) and the initial values of L and S and the parameter values from Table 1, is shown in Figure 1.[10] Both the level of the resource stock (the palm forest) and the size of the population are modeled over time. Figure 2 shows the dynamics of the model in a phase diagram, showing the convergence to the steady state. The gray line is drawn at the steady state value of the resource and the black line shows the convergence to the steady state. B&T further show that if the intrinsic growth rate of the palms, r, were higher, much like that of coconut and other palms that grow elsewhere in Polynesia, in the range of .35 instead of .04, then the model almost converges, but the cycles are so muted that adjustment paths are nearly monotonic. Even with intrinsic growth rates much smaller, around .15 to .2, any population "crash" would be too small to be noticed.

B&T extend their discussion to many other cases of civilization collapse, including the other mystery islands of Polynesia, where societies were known to have collapsed, as well as cases in Polynesia where intrinsic growth rates were higher than on Easter Island and collapse did not occur.

Table 1.[8] Parameter Values Used By Brander and Taylor

Parameter	Value
K	12000
Φ	4
b - d	-0.1
β	0.4
α	0.00001
r	0.04

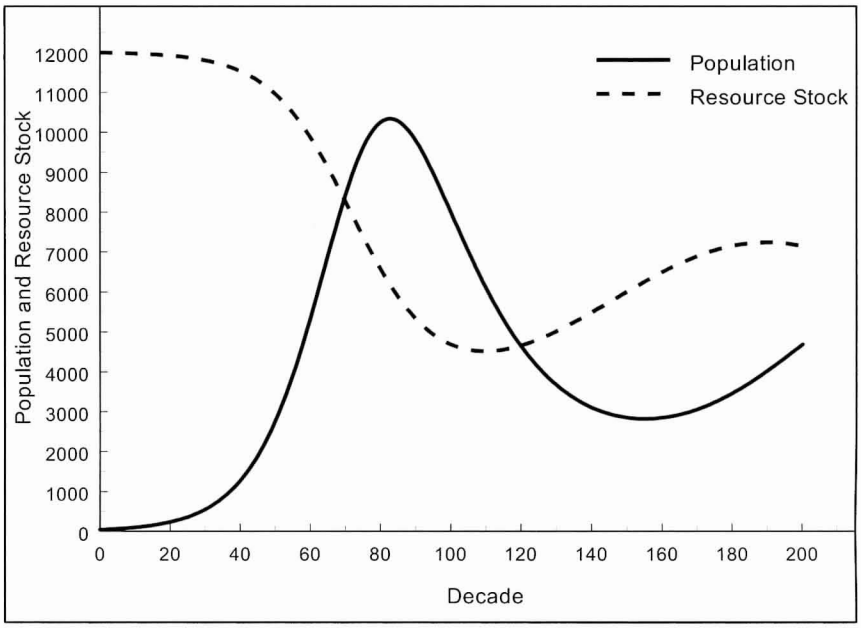

Figure 1. Brander and Taylor Case.

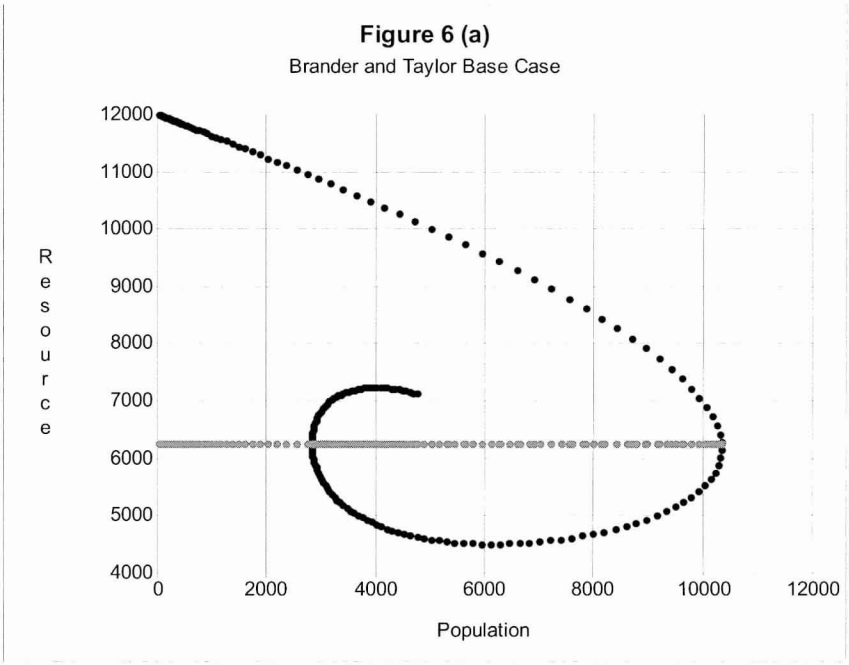

Figure 2. Phase Diagram.

[8] Brander and Taylor (1998) summarize the known prehistory of Easter Island and provide a detailed justification for the parametric values they use. See, in particular, pages 128-129. As mentioned before, research done since has cast doubt upon some of these parameters.

[9] Brander and Taylor (1998) relied on early carbon dating information, based on the Poike ditch charcoal carbon dating. Since Brander and Taylor, the opinion on first settlement of Rapa Nui has shifted from 400 A.D to around 800 A.D. or even later (Martinsson-Wallin and Crockford, 2001). However, Brander and Taylor also followed Mulloy and Figureroa (1978) considering that there was a single settlement of the island and its population evolved in isolation. This single-isolated-settlement theory has been challenged by Green (1998, 2000), Weisler (1998) and Martinsson-Wallin (1994). So if we replace Brander and Taylor's start date of 400 A.D. with 800 A.D. and add several hundred new settlers after that, the population and resource trajectories are near those of Brander and Taylor. In Figure 3 we show Brander and Taylor's model with an initial population set at 400 instead of an unknown number of injections of unknown numbers of immigrants at various unknown dates and original settlement beginning in 800 A.D. While the human population does not increase to around 10,000, as with the original parameters, the same pattern emerges. This may be because early establishing populations may have higher birth and lower death rate parameters than Brander and Taylor use throughout their work.

[10] This simulation reproduces the result obtained by Brander and Taylor (1998:129).

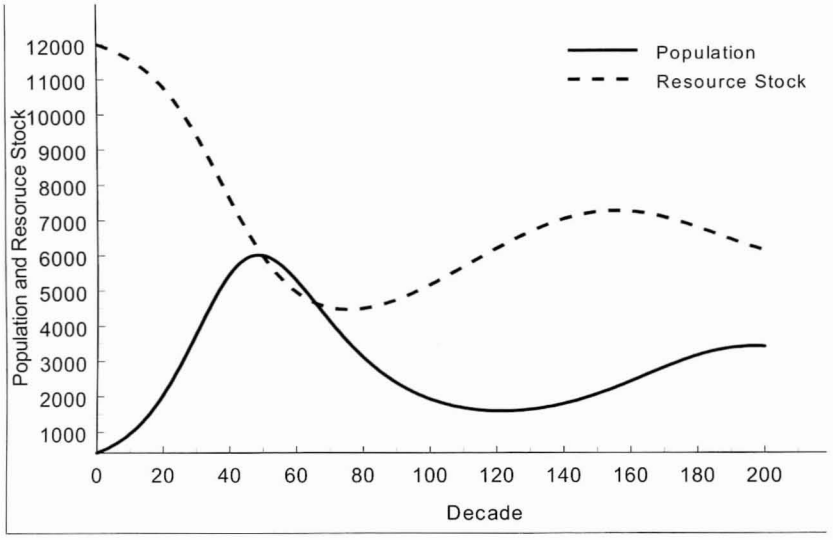

Figure 3. Brander and Taylor case, with initial population at 400 and original settlement in AD 800.

Social Institutions and Regulations

Rules and practices of a society, its institutions, can bring about a more sustainable system. Brander and Taylor, for example, note that institutional change might have avoided social collapse:

> …our analysis of Easter Island and the other cases suggests that economic decline based on natural resource degradation is not uncommon. Institutional change could potentially have averted the collapse in many of these societies but was not undertaken (or at least was not undertaken fast enough). Institutional failure in renewable resource use does happen and it has been fatal for several societies (Brander and Taylor 1998:134).

Such speculation is natural for economists because many of them view differences in economic prosperity as reflections of differences in institutional arrangements. The work of North (1990, 1991, 1994) and Williamson (1985) concentrated on the link between economic institutions and economic history. Institutions can affect economic development and the course of evolution in a number of ways: by influencing attitudes toward work, savings and investment behavior, risk taking, consumption propensities and other characteristics of producers and consumers.

The production (or harvesting) function for the resource stock is affected by the property-rights institutions. Price is the allocation mechanism in a market environment, inducing some sensitivity to changes in the size of the resource stock by its owners. However, the reaction of common-property owners and exclusive owners to changing resource stocks is quite different. Common-property owners surely recognize that harvesting is a zero-sum game: the more that is harvested by others, the less remains for them. The zero-sum nature of harvesting is an important consideration when a renewable resource stock can be exhaustively harvested. In this case, the common-property owners have an incentive to use the resource now before everyone else overuses it in the future, so the resource is overused now. While cooperation and self-regulation benefit the community as a whole by preserving resource stocks, personal gains accrue by cheating on agreed-upon harvest quotas while personal losses accumulate when others cheat. Consequently, a declining resource stock increases the percentage of time devoted to current harvesting when the stock is common property. The incentives are very different under exclusive, personal ownership institutions. In this case, the resource owner has an unambiguous desire to conserve the renewable resource. A declining stock decreases the percentage of time devoted to current harvesting under resource-ownership institutions because the resource owner is concerned both with current levels of consumption and with the future availability of the resource, both of which are under his control.

The Polynesian society that had developed on the larger islands situated in an archipelago adequately handled the resource allocation problem in more hospitable environments. At the time of the settlement of Easter Island, the society was somewhat egalitarian in the sense that everyone was guaranteed a minimum level of consumption through the institutionalized right of consumption by each person. Of course, in a hierarchical society, those of higher rank consumed more, but the consumption right was at the core of an economic system based on religious principles and rigid class distinctions. Often, this approach to economic activity involved the communal production of private goods. Herman Melville's (1921) description of the construction of a house in *Typee* illustrates the communal nature of this economy.

> At least a hundred of the natives were bringing materials to the ground, some carrying in their hands one or two of the canes which were to form the sides, others slender rods of the hibiscus, strung with palmetto leaves, for the roof. Every one contributed something to the work; and by the united, but easy, and even indolent, labors of all, the entire work was completed before sunset. (Melville 1921:298).

He also describes the typical approach to production and distribution. Fish harvests were consolidated and parceled out according to rank.

> The fish were quite small, generally about the size of a herring, and of every variety of color. About one-eighth of the whole being reserved for the use of the Ti [the aristocracy] itself, the remainder was divided into numerous small packages, which were immediately dispatched in every direction to the remotest part of the valley. Arrived at their destination, they were in turn portioned out, and

> equally distributed among the various houses of each particular district. (Melville 1921: 303)

The common pattern was to use communal production when possible and to redistribute other output periodically in order to equalize consumption levels among the population. Three classes of citizens shared in this distribution; the two primary classes were the aristocracy and commoners. While commoners could own land and produce some of the food and manufactured goods that they consumed, much of their production became communal property distributed by the chiefs. Personal ownership of the factors of production by commoners was severely limited. The chiefs, on the other hand, believed to be descended from the gods, had a divine right to dispossess the lower classes of their land and other goods. They further controlled the lives of the commoners by regularly collecting food and manufactured goods for redistribution. A third, intermediate status level evolved because the chiefs needed stewards to supervise this production and redistribution system. Marshall Sahlins (1958) explains the relationship between status and consumption.

> The three status levels were the focal points of the collection of larger and larger amounts of surplus food and manufactured goods and of their redistribution. A collection by a high chief necessitated prior collection by local stewards from, in turn, the commoners. Distribution followed the same pattern. Most of the goods so collected reached the producers eventually, especially goods collected for feasts (Sahlins 1958:16-17).

> Polynesian chiefs function as central agents in large-scale redistributions of food and other goods. All stewards, in fact, have this perogative, but the higher the rank of the chief, the greater his distributive activities in terms of the amount of goods and people encompassed. The redistributive process provides the economic basis for the celebration of great religious ceremonies, including the rites of crisis in chiefly families, and for other community activities, such as warfare and communal labor. In many areas it also provides the mechanism for distributing food in famine periods. To engage in redistribution, chiefs must have call upon the goods produced in the households of the community (ibid.:7-8).

The property rights structure was one of the right of consumption rather than one of resource ownership. Each individual received an amount related to his status, regardless of his individual productivity. The level of consumption of each individual was dictated by tradition and religious principles rather than the level of individual output. Aristocrats, for example, engaged in very little productive activity but generally received disproportionately large distributions. Little mobility among classes existed and productive tasks varied little over time or among the classes. Both the level of productive activity and the division of time among various tasks was fixed by tradition.

A basic reason that the feast-famine cycle plagued Easter Island was that the consumption-rights economy did not have sufficient flexibility to respond to changing environmental conditions because incentives to produce and incentives to forego consumption are weaker in a consumption-rights society than in one based on private ownership of resources. Institutional inflexibility in this case was the result both of ignorance about the underlying source of the resource depletion and of cultural rigidities that did not encourage individuals to properly incorporate available information about declining harvests into their production and consumption decisions. Both technological and institutional change requires innovation, and innovation requires many minds attempting to solve the problems that people face. Simon (1996) and Boserup (1965), as well as Dalton et al. (2005), suggest that the larger the regularly interacting population, the higher the rate of innovation. Easter Island probably did not have a population large enough to produce the level of innovation to surmount the Malthusian population problem. Falling harvests reflect poorly on the ruling class in a consumption-rights culture, calling into question both their divine right to govern and their sensitivity to the needs of the population. It is understandable in this institutional environment that the rate of harvesting is maintained as stocks fall since the political stability of the society is threatened by consumption shortfalls.

Diamond (2005) points out that, according to oral traditions, Easter Island's chiefs and priests claimed kinship to the gods, defending their elite status with promises of abundant harvests. As the population outgrew their deforested island's ability to support them, the promises of the elite began to ring hollow, leading to a revolt by military leaders in about 1680, destroying the hold of the existing political and religious establishment. With the overthrow of the chiefs and priests came the overturning of the elite's statues.

Ostrom (1990) and Ostrom, et al. (1994) provide persuasive arguments that efficient allocation mechanisms sometimes occurred in traditional societies, but that factors often conspire (in traditional and in more advanced societies) to thwart the evolution toward institutions that better preserve the resource base. The most important inhibitor of evolution toward more conservation is an absence of consensus about the source of the problem. For example, if the society incorrectly attributes crop failure to low rainfall when soil exhaustion is the problem, then it will seek institutional changes that can increase the frequency of rain. It will not focus on creating property rights structures to protect the land. Other factors that can influence the direction of change include the degree to which the changes create winners and losers and the cost of enforcing the changes. Changes that produce many losers will be resisted more successfully than changes that affect all parties similarly. Changes that are costly to enforce will probably not persist.

The Polynesian institutions that performed well on islands with hospitable soil and climatic conditions proved in-

sufficient to maintain society under less favorable conditions. For a variety of reasons, societies on Easter Island and the so-called "mystery islands," such as Pitcairn and Christmas, did not sufficiently adapt to the different environments. In order to sort out the influence of environment and institutions on the development of these economies, recent work has simulated the evolution of growth and development under various institutional assumptions in addition to the institutions that actually existed.

For example, Dalton and Coats (2000) examine the same Easter Island economy model as did Brander and Taylor but with a parameter representing the degree to which private property rights govern the use of the resource stock. As the property-rights parameter goes from an open-access commons to a private property-rights regime in the resource stock, the feast-famine cycle is dampened. They compare two institutional alternatives to the consumption rights society. The first is the traditional approach to open-access harvesting of the natural resource. Open access exists when the resource is considered the common property of the community and all citizens have an equal right to harvest it. This institutional framework provides for common ownership of the natural resource and protects the right of any individual to keep what is personally harvested. In addition to open-access harvesting, they examine a second alternative to consumption rights, the right of exclusive, personal ownership of the natural resource, or simply, private property rights.

Brander and Taylor do not predict, as an equilibrium, the state of affairs discovered by the Dutch at Easter Island in 1722. Rather than the small population surviving without its extinct resource, Brander and Taylor predict a stable equilibrium with positive levels of both population and the resource base. The Dutch found about 3,000 islanders but no trees. D'Alessandro (2005) predicts this outcome in a dynamic Ricardian model of two sectors based on an inexhaustible resource, "corn," and an exhaustible resource, "palm trees." Technological change that boosts the harvest, or an increase in the demand for palm trees, may bring this slowly growing resource to extinction. The diminished population then survives on corn, albeit with zero utility.

Most of the Easter Island economics literature assumes that people have equal access to the resource; that property rights to it are not well defined. D'Alessandro accepts this assumption but explores how varying regimes of ownership of corn (grain) land may affect the exhaustible resource. Her model incorporates "landowners," who receive *rents* from corn (rents are defined here as an excess of revenues above costs; and since there is no money in her model, revenues and costs must be understood in terms of physical goods, such as corn, so that rents become a difference between output and inputs valued in units of corn); and workers, who divide all product net of the rents. Property rights are said to be highly concentrated when landowners receive the entire rent, spending (trading) it solely on a luxury good produced with the exhaustible resource. (Workers may choose between the harvest and corn.) When property rights are diffused, harvesters may also receive part of the rent, which they spend on harvest and corn. Property rights are completely diffused when harvesters receive the full rent. Finally, D'Alessandro examines the case of no well-defined property rights, where land is common property, such as the exhaustible resource. All individuals are workers in this case.

When only a few individuals own land, the harvest is larger than in the other cases of property ownership, since the landowners demand luxury goods rather than corn. This outcome may exhaust the natural resource stock if the preference of workers for corn is weak, implying that they demand much harvest for subsistence. The exhaustible resource is more likely to be preserved in the case of diffused property rights, since this case implies a shift in demand from harvest to corn.

The Brander and Taylor model asserts a stable equilibrium with positive levels of population and of the resource base. They do not explicitly model a scenario that leads to extinction of the resource with a surviving population. Conrad (2005) develops a similar model where the ease with which a resource can be harvested is a factor and where the harvest may drive a renewable resource below the level at which it may sustain itself. Denote the resource as X; its intrinsic growth rate as r; the minimum level for the resource to sustain itself as K_o; the maximum level at which the resource may sustain itself – its carrying capacity – as K_1; and the effort in harvesting the resource as E. Then Conrad models the instantaneous change in the resource as

$$X = rX(X/K_0\text{-}1)(1\text{-}X/K_1)\text{-}qXE \quad (13)$$

where q expresses the ease in harvesting the resource. This "catchability coefficient" may also be interpreted as a technology parameter. The first term on the right-hand side gives the growth in the resource; the second term gives the harvest. Conrad finds that, if property rights are absent, then harvesting will drive the resource to extinction if

$$c/(p\text{-}s)q < (K_0+K_1)/2 \quad (14)$$

where c is the unit cost of harvest effort and p-s is the market price of the resource minus shipping costs. He finds that the resource is likely to become extinct if it is easy and valuable to harvest. Counter to intuition, the intrinsic rate of growth of the resource plays no role in Conrad's sufficiency condition for this equilibrium, a conclusion that bears on the Easter Island debate because Brander and Taylor (1998:129) argue that the island's resource base had been inhibited by its adoption of the slowly-growing Chilean wine palm. Conrad (2005) contends that the passenger pigeon in North America satisfied the sufficiency condition in the late 19th century, when it was destined for extinction, although he acknowledges that q is difficult to estimate due to a lack of data.

Regulations or policy may be able to bring about sustainability. It is natural to be optimistic: The growth function for the resource ($G(S) = rS(1 - S/K)$, where S is the resource stock and K is the carrying capacity) is symmetric about $S = K/2$, which determines the maximum sustainable harvest. A limit on the immediate harvest may allow the resource to grow so that it sustains a larger harvest than before, increasing utility.

However, a policy or regulation can affect a society only if it is actually adopted. If the policy requires people to reduce their consumption below the level of subsistence, they will ignore it. Brander and Taylor do not consider a subsistence level; in fact, they implausibly assume that if the resource base collapses, then people will continue to devote a fixed share of their time to manufacturing rather than allocating more time than before to harvesting the resource.

Pezzey and Anderies (2003) further modify the Brander and Taylor model by imposing a subsistence level of consumption. As the harvest per capita falls toward a minimum level of consumption, people began to harvest more and manufacture less. They note that Easter Islanders manufactured no more stone statues after about AD 1500. In the Pezzey and Anderies (2003) model, people only comply with taxes and regulations if they remain above subsistence. The researchers' results are discouraging. Allowing for a subsistence minimum increases the possibility of collapse; people struggle to survive by expending more effort on the harvest, a strategy that exacerbates the problem of inadequate resource growth.

But common-property regimes in some traditional societies appear sustainable. In the South Pacific kingdom of Tonga, on the island of Lofanga, people have apparently protected the fishery indirectly by adopting a scheme of informal insurance. Once the fisherman satisfies the needs of his family, he must share his remaining catch with the community. In effect, he pays an insurance premium for the times when he is sick or unlucky and must share the catch of others to survive (Bender et al., 2002). This insurance may prevent him from over-fishing on occasion in order to build up a stock that will see him through during illness. Bender et al. acknowledge that the insurance may also induce a moral hazard: confident that others will take care of him, the fisherman may refuse to fish.

Indigenous cultures may also develop rules for sustainability. Erickson and Gowdy (2000) tell of Tikopia, which stabilized its population at 1,000, apparently at the urging of its chief, whose annual proclamation called for zero population growth. This was before the Europeans arrived. The Tikopians also replaced slash-and-burn agriculture with fruit and nut trees and also eliminated pigs. In the 20th century, however, Christian missionaries exhorted the population to increase. By the 1950s, the population had exceeded the carrying capacity of the island. Cyclones during that decade were followed by famine and decimation of the population. Drawing from the experience of Tikopia, Erickson and Gowdy suggest that both resource conservation and institutional adaptation are important in achieving a stable population.

Anderies (2000) offers the Tsembega as counterpoint to Easter Island. The Tsembega, like the islanders of Tikopia, developed sustainable practices to manage common-property forest resources (and control their population). The Tsembega inhabit a mountainous area in New Guinea's Jimi and Simbai river valleys. Other groups who share the Maring language live in the same area of New Guinea, with whom they have both peaceful and martial interactions.

While the Tsembega raise pigs, pork is not an important food source for them. Instead, pork is important in their rituals and pigs perform an advanced warning function, much like canaries in mines. According to Rappaport (1968), pig and human populations both grow until the work for raising pigs becomes too great, at which point the pigs of the Tsembega begin to invade the gardens of their neighboring peoples. This often leads to the death of the owner of the pig at the hands of the invaded gardener. Records of these garden-revenge killings are kept so that they may be avenged at the next ritually sanctioned war with these neighbors. Pigs provide a meter of population pressure and provide an estimate of the number of people who must be killed to get to the "right" population size. When enough Tsembega have been killed, a *Kaiko* is called, which involves slaughtering most of the pig population, giving it to allies to help gain their support, and releasing the Tsembega from the taboo of conflict with neighbors. Warfare ends when both sides agree that there has been enough killing. The human and pig populations have been reset to a lower level, and the process starts all over.

Anderies changes the utility function for Easter Islanders from the Cobb-Douglas function used by B&T seen above as equation (4) to a Stone-Geary type function:

$$u = (h - h_{min})^{\beta} m^{1-\beta} \qquad (15)$$

where h_{min} is the per capita level of the harvest or resource good necessary for subsistence.

Anderies (2000) uses a Stone-Geary utility function that allows effort in harvesting to increase with increased scarcity beyond the subsistence level. He notes that as resource goods becomes scarcer, labor is used less in manufacturing and more in harvesting – delaying the date of any population crash, but making the crash more severe once it occurs. There is an abrupt cessation of manufacturing in his model, just as the Easter Islanders rather suddenly stopped *moai* construction (though it seems that they increased their manufacturing of tools of war at about the same time!)

Anderies suggests that it is more realistic to suppose that once the per person harvest falls below a certain threshold, a subsistence threshold, that the islanders turned their attention away from manufacturing and toward resource harvesting. This reduces consumption of manufactured goods as they become cheaper relative to harvested or resource goods, or alternatively, increase the proportion of labor devoted to the harvest as the resource good becomes so scarce that the population no longer can subsist on it.

Anderies suggests that the Tsembega institutions depend on their "geometry," or rather their spatial relationship with the rest of the environment – in particular, their proximity to neighbors on whom war can be waged to keep the population in check. He also suggests that the Tsembega solution may not have worked for Easter Island because of the difference in proximity to neighbors. While war was part of the solution for Easter Island, unlike for the Tsembega, there seemed to be no rules or taboos that governed how the war played out, leading to overshooting the martial solution. With Anderies' subsistence modification of the B&T Easter Island model,

collapse comes very rapidly. It is unlikely that anyone would have noticed a problem with their resource use; institutional change, even if implemented, would have come too late.

In the period of prosperity on Rapa Nui, chiefdoms often competed by having grander *moai* constructed. In a multi-chief regime, no single chief and no single tribal group has sufficient concern for protecting bird or tree species for the future, in the same way that no single fisherman has sufficient concern for the survival of fish species to prevent overfishing. However, after the collapse, the multi-chief regime was replaced by a single-chief regime with the birdman cult (Routledge 1917), in which the chief changed each year. This may have been the beginning of a more sustainable regime. We may never know for sure, because in the 1860s, which was somewhat early in this rebound period, ships arrived from South America and carried off approximately 2000 islanders to slavery. They were treated so poorly that most died within a year of capture. Europeans also introduced the islanders to a new religion, as well as to new germs, smallpox, which also killed many. In 1877 only 110 Rapa Nui islanders remained (Lee 2006a).

Technology, Population and their Interaction with Property-Rights Institutions

Early theories of economic growth were concerned more with investment in capital, which is investment in human tools and equipment. As the capital/labor ratio increases, there is more equipment per worker and workers become more productive and income per person increases. However, as the capital labor ratio increases, the rate of increases, output (or income) per person increases, but at a falling rate, so the rate of economic growth falls. Technological advances may keep economic growth rate from falling, though. First efforts in including technological change made arbitrary assumptions about the rate of technological advance, technology progressed, but it was independent, or exogenous, of the economic model. Technological changes were later explained within dynamic economic models as being due to factors, such as population, educational levels, and property rights institutions, especially intellectual property rights institutions, such as patents, as these institutions shape incentives to innovate, thus, technological change becomes endogenous to the model. See, for instance, Romer (1990) and Gailor and Weil (2000), and Binswanger (1978).

Lucas (1967) discusses aggregate technology growth in terms of an investment model and uses U.S. manufacturing data to show that interest rates affect the rate of productivity growth. Following Lucas, Binswanger (1978) examines technological growth within an investment framework, showing that different input price ratios lead to different paths of innovation, with higher relative wages leading to technological advances that tend to economize on labor. This is relevant to the Polynesian economy because the sustainability of harvests often depend upon investment in improved harvesting technologies. Investment is made in harvesting technology, since it leads to a greater expected appropriable return, as long as the discounted value of the expected returns exceed the cost of the investment. If the return is not appropriable (because supportive property-rights structures do not exist), then the investment is not made. This applies as well to investments in technology that can increase the growth rate of a renewable resource or to increase the carrying capacity of environment.

Boserup (1965) discusses the role of population growth in changing relative prices of final goods; these price changes lead to changes in agricultural practices and growth in food supplies. Simon (1996) points out that higher population and technology growth are positively related for two reasons. First, technological advances bring about temporarily higher per capita incomes that lead to higher populations. Second, following Boserup, Simon suggests that population growth leads to higher demands for final goods, inducing technological advance, an idea well expressed by the saying "necessity is the mother of invention." Technological growth depends on conditions other than just population growth. Simon (1996:372-73) points out two mediating factors to the population-technology relationship: the rule of law and the incentives that implies an educational attainment.

Reuveny and Decker (2000) observe that the two standard approaches for escaping the Malthusian fate are modifying human institutions and changing technology. They analyze the effects of technological progress and changes in fertility through population control reform within the basic parameters of the B&T model. They examine three indicators: population, the renewable resource stock, and per capita utility. Their simulations analyze both steady-state equilibria and inter-temporal processes.

Technological change in resource growth leads to resource stability with either logarithmic or exponential progress, and human population stability in the case of logarithmic progress, and population growth with exponential progress. Obviously, the Malthusian disaster strikes earlier and more catastrophically when technological progress occurs in harvesting. The fluctuations in population and resource stock are greater than in the base case with logarithmic progress, and the human population is obliterated with exponential progress. Reductions in fertility rates through some sort of social control lead to smaller fluctuations in population and the resource stock, converging to a smaller human population and a larger resource stock. All in all, Reuveny and Decker (2000) do not find much hope for technological progress solving the Malthusian problem, but rather, greater hope for a solution in population control.

Decker and Reuveny (2005) alter their technological progress model (Reuveny and Decker 2000) to take into account the views of Boserup (1965) and Simon (1996) who have suggested that technological progress should be thought of as endogenous to the human social system and as related to both the degree of resource scarcity and to the size of the human population. For instance, as Diamond (2005) points out, there is evidence that Easter Island farmers developed lithic mulched gardens to reduce evaporation in their soil (also see Stevenson, et al. 2005 and Stevenson and Haoa 1998). Decker and Reuveny show that Boserup/Simon endogenous technological progress, when applied to harvesting efficiency, carry-

ing capacity and resource growth rate, fail to save Easter Island from its ruinous collapse.

Decker and Reuveny (2005) model technological progress as a stock variable that accumulates over time and that cannot be negative. When examining the steady state of their dynamic system, they find that there are no interior solutions. Instead, these are only two corner solutions: one in which both people and the resource have vanished, and the other where the resource has grown to its carrying capacity because the human population disappeared before having a chance to push the resource stock to extinction.

Decker and Reuveny (2005) conduct four simulations. The first is the Brander and Taylor base case with no innovation; the second involves innovation in harvesting, carrying capacity and resource growth separately, as did their Reuveny and Decker (2000) work. Third, they examine each of these cases under different assumptions about the roles of population size and resource scarcity in promoting technological progress. Finally, they consider different combinations of growth in harvesting, carrying capacity and resource growth. Their results with endogenous growth do not vary substantially from their results with exogenous growth. Compared to the Brander and Taylor base case, human populations are sustained longer and in better condition when there is technological progress in the resource growth rate, while people do worse than in the base case when there is technological progress in harvesting.

At first, it may appear that a cutback in consumption must surely extend the life of the resource. However, part of the unconsumed resource may be devoted instead to the manufacture of investment goods. If a tree is not cut down for firewood, it may serve instead to produce canoes. A high savings rate that finances investment goods may thus hasten the end of the resource. Anderies (2003) confirms this intuition in a dynamic analysis of an economy that has two sectors (agriculture and manufacturing) and that equates savings to investment. Under some conditions, moderately high savings rates lead the economy into perpetual overshoot and collapse. Extremely high savings rates, however, lead to a stable equilibrium: When people save most of their income, they eat little, so the population grows too slowly to strip the resource.

Anderies (2003) explicitly models the demographic transition, which is the change in a society from one with a high rate of population growth accompanied by a high mortality rate to one with a low rate of population growth accompanied by a low mortality rate. As discussed, moderate savings rates in his model may lead to boom-and-bust cycles, because they enable firms to procure exhaustible resources for manufacturing investment goods. But boom-and-bust need not result if the increase in income leads to a sharp decrease in fertility and thus in new demand for the resource. In fact, the economy may converge to a stable equilibrium, despite moderate savings.

Like Reuveny and Decker, Anderies is skeptical that technological change can permanently avoid overshoot and collapse. In his 2003 model, random improvements in productivity merely hasten the onset of boom and bust, by stepping up production and thus overusing the resource.

What about innovations that reduce the harvest rate for a given level of production? Anderies (2003:237) reports on the scenario in which new technology can reduce the economic impact on the resource indefinitely. That impact, he finds, will approach zero in five generations while the population will grow perpetually. Anderies dismisses this outcome, without explanation, as "implausible". It is more likely that the laws of physics will confound further technological progress, which may bring us back to overshoot and collapse; or that an exogenous constraint, like global warming, will slow growth; or that nations may adopt population controls.

Dalton, Coats and Asrabadi (2005) extend the analysis of institutional reform on Easter Island by incorporating Simon's insights about the relationship between technology and institution. Like Binswanger, Dalton, Coats and Asrabadi focus on the technologies that may be developed and the role of relative prices in the mix of developed technologies. They look at two dimensions for technological development in the Brander and Taylor model: technologies that increase the growth of the resource and those that increase the harvest rate. If the harvested resource is a common-property resource, then the payoff of increasing the growth rate of the resource is likely to be far below the payoff of increasing the harvest, so technological development will be greater in efforts that increase the harvest rate than in efforts that increase the rate of growth of the resource. They show that private property rights in the resource encourage growth in the resource relative to harvesting it, subduing the feast-famine cycle.

War, Appropriation by Violence

One may expect that, as a resource such as a forest becomes scarcer, people will devote more time to appropriating the resource through violence. There are three basic ways in which people can elicit cooperation from others for the use of resources: trade, charity, and force. Economic theory suggests that people will use the least costly means at their disposal to reach their goals, so that if they find the total costs, including the moral or psychological costs of doing wrong, of acquisition by violence to be less than the costs of acquisition by trade, then they will choose violent means. The cost of using violence includes the risk of placing oneself in harm's way in addition to the risk of being caught and punished by authorities. When a person's chance of survival falls (without resorting to violence) to a very low level, then his costs of using violence, in terms of placing himself in harm's way, falls as well, as he has little to lose.

Malthus noted that famine and war were checks on population growth. Famine and its results, of course, are examined in the basic Brander and Taylor (1998) model. We have already discussed the institutions of the Tsembega and how their institutions led to population control through scheduled or triggered violent conflicts. Anderies (2000). Maxwell and Reuveny (2000) and Grossman and Mendoza (2003) examine resource scarcity as an important factor contributing to violent conflicts.

Maxwell and Reuveny (2000) note the increased pressure that the world's population places on its resources and

they ask how societies might react to increasing resource scarcity. In less developed societies, property rights are often poorly defined and enforced, technology investments cannot be made because of their extreme poverty and people depend heavily on the ecosystem. In their model, conflict has three effects. Unlike Anderies (2000, 2003) and Pezzey and Anderies (2003) who assume that when the resource harvest reaches a certain minimal state that increased resources will be devoted to harvesting, Maxwell and Reuveny use a minimum per capita harvest to trigger a state of violent conflict. This leads to a diminution of resources devoted to harvesting, since conflict redirects labor from production to violent appropriation. Conflict reduces population pressure on resources by increasing the death rate. It may also cut the resource growth rate.

Maxwell and Reuveny find that conflict due to scarcity does not continue forever. Population and the resource base might settle to a steady-state equilibrium that assures no future scarcity-based conflict. External shocks can increase resource scarcity, triggering conflict. Technological change can either increase or decrease the chance of resource-based conflict, as some technologies weaken the resource stock and others may strengthen it or help to curb population growth, such as birth control technologies. Surprisingly, Maxwell and Reuveny find that high resource growth rates may actually increase the duration of conflict, though scarcity-induced conflict is less likely. The higher duration of conflict occurs because the population does not fall as quickly.

Grossman and Mendoza (2003) demonstrate this formally. They show that if each person spends the same share of time harvesting, the resource endowment is fully exploited when people maximize the current utility of consumption as well as the expected utility of survival (assuming that everyone has the same utility function). If the resource is scarce enough, and survival is valuable enough, then everyone spends all of his time harvesting. Even when one splits his time between harvesting and leisure, he will harvest a lot more when the resource becomes scarce or when he expects the resource to become abundant (because this increases the value to him of survival). Paradoxically, if he expects the resource to become more abundant, then he may devote so much time now to harvesting that his total utility over time drops.

The utility function used by Grossman and Mendoza is unusual in this literature. Papers typically assume, after Brander and Taylor, that people will maximize instantaneous utility in the absence of property rights to protect their claims to future utility. Another innovation of Grossman and Mendoza is to model explicitly the impact of consumption on survival.

Other findings

The work in economics, using Brander and Taylor's model, has been theoretical with little more than case studies as verification. However, there has been work done concerning Easter Island by those in the social sciences. In a book recently reviewed in this journal (V. Lee 2005), Diamond (2005) provides an excellent overview of the apparent history of Easter Island, based on the essential archaeological literature, as well as on the modern post-European history of this mysterious island. Among the details Diamond discusses is the evidence of agricultural intensification – that is, technological advancement from irrigation technologies, stone chicken houses, and rock gardening or lithic mulch agriculture found in many arid regions – to reduce the evaporation of moisture from the soil, to provide slow-release fertilizer through leaching of minerals from the stones, and to reduce the variability in soil temperatures.

Rolett and Diamond (2004:445), using various statistical models of deforestation and forest replacement over 69 Polynesian islands in the Pacific, find support for Brander and Taylor's contention that it was the climate and growing conditions on Easter Island that brought about its collapse. They conclude that, "Easter's collapse was not because its people were especially improvident but because they faced one of the Pacific's most-fragile environments." Diamond (2005) notes that only three islands in the Hawaiian chain – Necker, Nihoa and Ni'ihau – come close to Easter in the extent of deforestation suffered, islands which are all much drier than Easter, and that there is little evidence to suggest that Necker ever had trees.[11]

Diamond (2005:115) credits his co-author, Barry Rolett, in their work in *Nature* (Rolett and Diamond 2004) for combing through journals of early explorers and finding descriptions of the islands and acquiring a metric for deforestation on 81 islands. They tabulated nine physical factors that had sufficient variation to explain different deforestation outcomes. Diamond (2005) summarizes these factors as:

- moisture
- cooler high-latitude islands vs. warmer equatorial islands
- old vs. young volcanic islands (the latter have better soil)
- aerial volcanic ash fallout (again, nutrient)
- island altitude
- remoteness or proximity to neighbors – the people of remote islands have no neighboring islands to visit, to trade with, so they have more time to devote to deforestation activities, *moai* construction.
- small vs. big islands
- islands near or far from Central Asia's dust plume
- islands with and without *makatea*. (Makatea is an island of coral, where volcanoes pushed a reef up from the ocean.)

Rolett and Diamond's 2004 statistical work predicts that the most deforested islands would be Easter Island and the dry, deforested Hawaiian Islands of Necker and Nihoa.

Diamond (2005:119) states:

[11] Georgia Lee (2006b), in correspondence, notes that the Hawaiian island of Kaho'olawe also suffered severe deforestation.

> The parallels between Easter Island and the whole modern world are chillingly obvious. Thanks to globalization, international trade, jet planes, and the Internet, all countries on Earth today share resources and affect each other, just as did Easter's dozen clans. Polynesian Easter Island was as isolated in the Pacific Ocean as the Earth is today in space. When the Easter Islanders got into difficulties, there was nowhere to which they could flee, nor to which they could turn for help; nor shall we modern Earthlings have recourse elsewhere if our troubles increase. Those are the reasons why people see the collapse of Easter Island society as a metaphor, a worst-case scenario, for what may lie ahead of us in our own future.

Of course, the metaphor is imperfect….

Diamond also mentions that our technological abilities to over-harvest, over-fish, over-hunt, and destroy the very resources that allowed our population to grow so great, far surpasses the technologies available to those on Easter Island. In his final chapter, Diamond claims that he is neither a pessimist nor an optimist; instead, he remains cautiously optimistic because he sees people making very long-term plans that often involve immediate sacrifice.

Conclusions

Economists have studied the collapse of Easter Island and developed and modified mathematical models to simulate population and resource use, not for the sake of Easter Island itself, as certainly these models are not intended to predict future economic conditions on Rapa Nui, Rather, economists intend to use the island, as did Bahn and Flenley in the title of their 1992 book, *Easter Island, Earth Island*, as a metaphor for the planet. Perhaps the prevailing view of economists working with Brander and Taylor's (1998) model of Easter Island is well summed up by Decker and Reuveny (2005:120) who suggest that they

> …do not seek to contribute to knowledge on Easter Island per se, and our analysis could be developed with respect to a purely 'hypothetical' closed system. However, the traditional environmental interpretation of the Easter Island collapse suits our purposes here.

Malthus pointed out that human populations tend to outstrip their ability to sustain themselves, but that famine is not inevitable, as institutions and war can keep the starvation equilibrium at bay. Since Malthus, some work, such as the Club of Rome's well-known *The Limits to Growth* (Meadows et al. 1972), present a very pessimistic view of the future of mankind, predicting plummeting resource availabilities, incomes and populations. These dire predictions mirror what many think occurred on Rapa Nui.

Since Malthus, technology has been seen by some, such as Julian Simon (1996) as potentially saving us from collapse. Trade and migration, along with institutions, technology, war and even famine have kept the entire Earth from being driven to constant famine. But the Earth is as much a closed system as was Easter Island, and trade and migration can only stave off local disaster. Perhaps technology can push back the day of reckoning, but social institutions of some sort are all we have, in the end as a means of combating population pressure. Even for technology to flourish, the rule of law and property institutions must be well established so that people have an incentive to be innovative; also, an educated population must be in place. We should also be careful not to trust that we can use institutional means that work well in large, modern societies in societies that are less advanced. Similarly, what works for a small, isolated society may not work in a large, diverse, but interconnected global society.

Diamond is correct in noting that the metaphor, "Easter Island as Earth," is less than perfect. For one, those on Easter Island did not have the technological capabilities that we have, such as technology that allows us to do better at conserving resources. Also, in its prehistoric period, it now seems that Easter Island had much more interaction with the other Pacific islands and with South America than the earth will have with beings and places beyond earth's boundaries. More importantly, however, Easter Islanders did not have the results of institutional experiments conducted in thousands of societies at their disposal for review. In many parts of the world, population growth rates have fallen, with sub-Saharan Africa remaining the most problematic, so that it seems many areas have begun to enter the stage of demographic transition, with both falling death rates and even greater declines in birth rates. Greater individual responsibility for the care and expense of children, instead of allowing these costs to be borne by the society as a whole, enables us to avoid the overpopulation problem Hardin (1968) discussed in his "The Tragedy of the Commons." By changing the responsibility of bearing and raising children from a "commons" where the society at large bears these costs, to one of individual responsibility, incentives to have children are drastically reduced (for instance, see Tietenberg 2004).

By the same token, removing resources from the realm of "the commons" enhances sustainability. In a commons, the price of harvestable resources only reflects the cost of harvest and not the cost of future scarcity. The price of resources under private property rights includes a return due to expected future scarcity, the individual owner weighs extracting or harvesting now and selling at today's prices against the future price available from harvesting and selling in the future. The demands of future generations are carefully weighed in the process, boosting the price and cutting current consumption so that the resource will be available for the future. While Easter Island is an important metaphor for the earth and the possibility of social collapse from over-harvesting resources, the story of societal collapse of Easter Island could be mere myth. The population collapse may have had its roots in some sort of invasion. Rainbird (2002), for instance, suggests that contact with Europeans led to Easter Island's partial, but dras-

tic, depopulation. Other possibilities abound (see Diamond, 2005).

We know that the dreadful fate of those who occupied Easter Island during its social upheaval cannot be changed, but perhaps, by studying likely paths of population and resource stocks over time and comparing these paths to those based on predictions made from altering certain parameters of the model due to institutional and technological change, we can learn ways to avoid making Easter Island's past Earth's future.

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