Conflict and Renewable Resources

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The economic literature on conflict employs a static, game-theoretic framework developed by Jack Hirshleifer. The authors introduce conflict dynamics into a model with two rival groups, each dependent on a single contested renewable resource. The model is based on two stylized facts: conflict often arises over scarce renewable resources, and those resources often lack well-defined and/or enforceable property rights. In each period, groups allocate their members between resource harvesting and resource appropriation (or conflict) to maximize their income. This leads to a complex nonlinear dynamic interaction between conflict, the two populations, and the resource. As developed, the model relates most closely to conflict over renewable resources in primitive societies. The system's global dynamics are investigated in simulations calibrated for the historical society of Easter Island. The model's implications for contemporary lesser developed societies are examined.

1. INTRODUCTION

The economic literature on conflict can be traced back to Malthus ([1798] 1970), who argued that conflict over natural resources would arise as a consequence of population growth and environmental degradation. Contemporary studies have moved away from a focus on natural resources. Recent advances in the literature can be traced to the seminal, game-theoretic model of Hirshleifer (1989). Hirshleifer-type models, including ours, share two central features. First, there is the lack of secure individual or group property rights. Second, conflict is understood as a rational activity. Actors may devote effort to create wealth through production and/or appropriate the wealth of rival actors through conflict. A third common feature of Hirshleifer-type models is that they are static. We, however, offer a dynamic model of conflict that concentrates specifically on the dynamic interplay between conflict and the contested wealth.

The economic literature on conflict has abstracted from modeling the underlying source of conflict and conflict dynamics. Although this abstraction allows authors to claim applicability to many conflict situations, it weakens the ultimate predictive power of the models, giving rise to questions that the current literature fails to address. For example, once groups are in conflict, does a rise in the contested wealth lead to a

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lessening or a strengthening of conflict? How does conflict affect (or, how is it affected by) changes in the allocated effort and/or contested wealth over time? Our dynamic model of conflict allows us to gain insight into these questions. We study conflict dynamics within the context of conflict over renewable resources. However, our approach could be applied to other Hirshleifer-type models.[1]

Our model features two rival groups. Each group is dependent on a single contested renewable resource. In each period, the groups allocate their members between resource harvesting and resource appropriation (or conflict) to maximize their incomes. This leads to a complex nonlinear dynamic interaction between the two populations and the resource. The complexity arises in part because of our decisions to model the disputed resource as renewable and assume that the resource is essential for procreation. These decisions are motivated by a desire to probe the model's implications for conflict in lesser developed societies that closely depend on the environment for livelihood.[2]

In recent years, many social scientists have argued that renewable resource scarcity (e.g., land degradation, deforestation, fisheries depletion, food scarcity, and water scarcity) is increasingly a factor that contributes to political conflict.[3] In the post-1945 era, conflict over renewable resources has typically occurred in lesser developed countries (LDCs). For example, turmoil in Haiti has been linked to deforestation (Wallich 1994; Homer-Dixon 1999). Land scarcity and deforestation are said to have played a role in the 1994 Rwandan civil war, whereas land pressures and hunger stimulated the Chiapas uprising in Mexico in the early 1990s (Renner 1996; Baechler 1998; Brown, Gardner, and Halweil 1999).[4] Other examples involve conflict over scarce water. Some observers in fact argue that future wars will be increasingly about water.[5] Conflicts

1. Although we focus on renewable resources, as noted by Hirshleifer (1995) and Neary (1997), Hirshleifer's setup could be used to analyze many situations, including gang warfare, criminal-victim interactions, labor disputes, legal disputes, and animal territoriality disputes. Using a static model, Neary motivated his general-forms Hirshleifer-type model by referring to Homer-Dixon's (1999) review of real world conflicts over renewable resources.

2. Conflict over nonrenewable resources also exists. For reasons of tractability, however, our model has only one resource. The resource is meant to capture the entire basket of resources on which a primitive society depends. Given this dependence, it is appropriate to model the resources as renewable, because most life-giving resources are renewable.

3. Scholars suggest four channels through which this tends to happen: a decline in economic performance, ethnic clashes due to population migration, a weakening of political institutions, and a general exacerbation of existing socioeconomic-political cleavages. For reviews of theories and case studies, see Myers (1993), Baechler (1998), and Homer-Dixon (1999).

4. This list is by no mean exhaustive. For example, social strife in the post-1945 Philippines has been linked to deforestation and land degradation leading to population displacements (Hawes 1990). Durham (1979) described how land scarcity caused migration from El Salvador to Honduras, resulting in competition between immigrants and natives over land and leading to a war in 1969. Subsistence crisis in Peru led to the Luminoso rebellion (McClintock 1984). Since the 1970s, cropland and food scarcities have aggravated ethnic conflict along the border between India and Bangladesh (Ashok 1996). Since the 1980s, there has been a rise in piracy directed at fishing boats in lesser developed countries (*Oceans and the law of the sea* 1998), and land pressures have stimulated squatters on ranches in Brazil (Brazil: Land for the landless 1996).

5. See, for example, the press release by the World Bank's vice president, Ismail Serageldin (1995). Contemporary cases include the 1989 Mauritania-Senegal conflict, the ongoing Arab-Israeli conflict, the mid-1980s South Africa–Lesotho conflict, the ongoing Syrian-Turkish conflict (Myers 1993; Homer-Dixon 1999), and the 1990s social strife in China's Ningxia province (Pomfret 1998).

over renewable resources have also occurred among developed countries (DCs) but with lower intensity (e.g., the 1972–73 English-Icelandic Cod War; recent U.S.-Canada or Canada-Spain fishing conflicts).[6]

Due to its tendency to describe specific episodes of conflict, the extant literature on conflict over renewable resources in political science has generally neglected the complex dynamic interplay between population, natural resources, and conflict. Our stylized model allows an investigation of this interplay, which can take relatively long periods of time to play out.[7] Thus, our model contributes to three literatures. Our chief contribution is the dynamic extension of the static, game-theoretic conflict framework of Hirshleifer (1989). We also extend the literature on the dynamic interplay (absent conflict) between population and resources by admitting conflict as a rational economic activity. In this literature, the studies of Prskawetz, Feichtinger, and Wirl (1994); Milik and Prskawetz (1996); and Brander and Taylor (1998) are particularly relevant to our study. These studies employ a similar predatory-prey setting, where man is the predator and a renewable resource is the prey. Finally, we contribute to the literature on resource scarcity and conflict in political science by providing insights on the system's dynamic behavior while in conflict.

The article proceeds as follows. In section 2, we review the literature and discuss our contribution. In section 3, we develop the model. In section 4, we consider various modeling extensions. In section 5, we analyze our model in the context of the Easter Island society and evaluate its implications for other societies. Section 6 concludes the study.

2. THE ECOLOGICAL COMPETITION AND CONFLICT LITERATURES

Two bodies of literature are relevant for our study, namely, the ecological competition literature and the economic literature on conflict. The first body of literature contains a class of dynamic models aimed at representing competition between two interacting species that feed off the same renewable resource. Arising from the works of Lotka (1924) and Volterra (1931), these models are specified as a system of equations of motion (or differential equations) for the stocks of each of the two species and a resource stock. Lotka and Volterra assumed that a rise in the size of either species reduces the resource stock, whereas a rise in the size of one species reduces the size of the other.[8]

Some scholars find analogies between ecological competition and economic situations. However, in the Lotka-Volterra model, the population numbers of one species

6. Choucri and North (1975) argued that land pressures in Europe caused World War I, and Westing (1986) listed wars from 1914 to 1982 involving developed countries and natural resources.

7. Maxwell and Reuveny (2000) studied the dynamics of conflict over renewable resources, but they did not model the conflict decision.

8. Depending on their parameters, the Lotka-Volterra trajectories oscillate over time, converging to one out of five steady states. In one steady state, the two populations and the resource coexist. In the second and third, only one population exists, respectively. In the fourth, both populations vanish; and in the fifth, the population and resource vanish. See, for example, MacArthur (1972) and Slobodkin (1980).

respond automatically to the numbers of the other species.[9] This behavior makes this model a less attractive tool for studying human behavior. Although we employ elements of ecological competition, we add to them the notion of optimization.

Turning to the economic conflict literature, Hirshleifer (1989) developed a one-period game-theoretic model in which conflict is treated as a rational activity. Studies using this framework typically include two rival groups modeled as unitary actors. Hirshleifer's initial framework has been extended in various ways, including allowing for trade among rivals, the consideration of various conflict interaction protocols (e.g., Stackelberg) and nonunitary actors.[10] However, each of these extensions employs a static framework. There are no equations of motion, and the time trajectories of variables are not analyzed. Several authors are aware that this is a limitation of Hirshleifer's approach and have called for its extension to the dynamic case.[11]

We believe our study is the first to explicitly introduce dynamics into Hirshleifer's work. However, the general issue of conflict dynamics has been considered in prior work. Usher (1989) developed a model in which a society moves between states of anarchy and despotism. Yet, only population has an equation of motion, the state of anarchy is simply assumed to be transitory due to the high costs it imposes on actors, and the model is not solved explicitly. A few other studies employ a two-period game-theoretic model. For example, Brito and Intriligator (1985) studied the circumstances under which conflict over the rights to a flow of a single good leads to war. In Skaperdas and Syropoulos (1996) and Garfinkel and Skaperdas (2000), the factors allocated between conflict and production in the second period of the game are assumed to be positively related to the payoffs received in the first period. These models are basically static, however, because the game is played only once. Recently, Hausken (2000) has studied the mismatch between individual and group interests in a Hirshleifer-type model. His model also is basically static, computing numerically the one-period equilibrium solution successively as did Hirshleifer (1995), which we discuss next.

Hirshleifer (1995) argued that the literature considers only a one-time allocation of resources between conflict and production but that his study examined continuing conflict.[12] However, he did not specify equations of motion, employing instead the one-period solution in successive iterations. Moreover, the condition he identified as determining dynamic stability is not derived based on standard dynamic analysis but rather is the condition ensuring the existence of a one period–based internal solution, an issue to which we will return later.[13]

9. For studies that find analogies between ecological competition and economic situations, see, for example, Jacquemin (1987) and Hirshleifer (1977).

10. Works in this area include, among others, Hirshleifer (1991, 1995); Skaperdas (1992, 1996); Grossman and Kim (1995); Skaperdas and Syropoulos (1996); Neary (1997); Anderton, Anderton, and Carter (1999); Garfinkel and Skaperdas (2000); and Hausken (2000).

11. See, for example, Skaperdas (1992), Grossman and Kim (1995), and Hirshleifer (1995).

12. See Hirshleifer (1995, 29).

13. Hirshleifer (1995, 47) acknowledged that his "steady state assumption rules out issues involving *timing*, such as arms races, economic growth or (on a smaller time scale) signaling resolve through successive escalation."

We study the dynamic interaction between conflict, population, and resources in a lesser developed society. The optimization component of the model extends Hirshleifer's work. From the ecological competition literature, we draw the idea that our model should have equations of motion for the rival populations and the contested good. However, in our model, the population sizes do not respond automatically to each other. Instead, they are affected by the actors' optimal allocation choices, as in the nonconflict models of Prskawetz, Feichtinger, and Wirl (1994); Milik and Prskawetz (1996); and Brander and Taylor (1998).

In our model, parties fight over wealth not only for instant gratification but also for the ability to invest their spoils to increase their own resource pool in the future. This pool is then available for future productive and conflictive activities. In a dynamic setting, therefore, it is necessary to link each group's spoils to its effort pool to be allocated in subsequent periods. In our setup, the allocated effort is population. Hence, the model has differential equations for the two populations, and each equation includes the spoils of conflict of the particular group as an input.

The production of wealth (resource harvesting in our case) also may require inputs that cannot be easily redirected for use in conflict. Often, the usage rate of these inputs has an impact on their availability in future periods. In our case, this input is given by the renewable resource stock, which is an input into the harvesting production process together with labor. Thus, the model distinguishes between these two inputs and tracks their interactions and availability over time.

Our approach could be applied to other Hirshleifer-type models, but it is not without limitations. To the extent that property rights could be enforced, an economic model of conflict might allow for interacting choices of optimal time-path decisions, in which actors take into account future incomes. In our model, there is optimization-based decision making, but the actors do not take into account the future consequences of their chosen actions. We believe our approach is appropriate in a model of conflict over resources in lesser developed societies that feature ill-defined or unenforceable property rights. We defer the development of a dynamic model featuring farsighted actors to future research.

3. THE BASIC MODEL

This section first develops our model and then investigates its properties in three respects: steady states solutions, comparative statics, and model's dynamics.

3.1 MODEL DEVELOPMENT

The model features two groups with population sizes of $N_1(t)$ and $N_2(t)$ in period t. Each group harvests from the same resource. The groups then engage in conflict over the total harvest. Population is allocated each period between harvesting effort (E) and conflict effort (F) to maximize the group's income. Conflict entails reduced harvest but also results in the appropriation of a portion of the rival group's harvest. Each group fully utilizes its population. Thus, $N_1(t) = E_1(t) + F_1(t)$ and $N_2(t) = E_2(t) + F_2(t)$.

Each group's harvest level, $H_1(t)$ and $H_2(t)$ is given by

$$H_1(t) = \beta R(t)E_1(t) \tag{1}$$

$$H_2(t) = \beta R(t)E_2(t). \tag{2}$$

Equations (1) and (2) illustrate that the harvest depends on the resource stock (R), the harvesting effort (E_1 or E_2), and a parameter denoting the efficiency of harvesting (β).[14] For now, we assume each group possesses the same harvesting efficiency. We explore the impact of differences in β in section 4.

The total harvest, $H(t) = H_1(t) + H_2(t)$, is contested by both groups. In Hirshleifer-type models, the payoff (the portion of the contested good won by each group) depends on the group's relative allocation of effort to conflict. We define $P_1(t)$ and $P_2(t)$ as follows:

$$P_1(t) = \frac{\alpha_1 F_1(t)^m}{\alpha_1 F_1(t)^m + \alpha_2 F_2(t)^m} \tag{3}$$

$$P_2(t) = \frac{\alpha_2 F_2(t)^m}{\alpha_1 F_1(t)^m + \alpha_2 F_2(t)^m}, \tag{4}$$

where α_1 and α_2 denote the efficiency of conflict effort of the two groups, and m is called the decisiveness parameter.[15]

Equations (3) and (4) are typically denoted as contest success functions. These functions have been interpreted in the conflict literature as either determining the proportion of the total prize going to each side or the probability of winning the entire prize. We adopt the former interpretation. As noted by Skaperdas (1996) and Garfinkel and Skaperdas (2000), many studies set $m = 1$ and $\alpha_1 = \alpha_2 = 1$. Hirshleifer (1995) set $\alpha_1 = \alpha_2 = 1$ and examined the impact of changes in m. In this section, we set $m = 1$ and assume that α_1 and α_2 are positive. We investigate the impact of changes in m in section 4.[16]

14. This technology was proposed by Schaefer (1957) and is popular in the resource literature (e.g., Clark 1990, chap. 1; Brander and Taylor 1998). Expressions (1) and (2) assume that each group's harvest is independent of the harvest of the rival group. Although this assumption is likely to hold when the resource is in abundance, when the resource is scarce, each group's harvest may impose a negative externality on its rival's harvest. Although our assumption has been made principally for analytical tractability, it is worth observing that the marginal return to harvesting effort, βS, falls as the resource declines.

15. The parameters α_1, α_2, and m are positive (Hirshleifer 1989, 1991, 1995).

16. In some studies, including his 1989 paper, Hirshleifer set $m = 1$. Although many Hirshleifer-type models are based on equations (3) and (4), some studies specify these equations as general forms: as, for example, in Neary's (1997)

$$P_1 = \frac{f(F_1)}{f(F_1)+f(F_2)},$$

where f is twice continuously differentiable. We employ a specific form to be able to compare to Hirshleifer's work and because we investigate the dynamics in numerical simulations.

The income of each group (Y_1 and Y_2) is given by the portion of the total contested harvest it wins:[17]

$$Y_1(t) = P_1(t)H(t) \tag{5}$$

$$Y_2(t) = P_2(t)H(t). \tag{6}$$

We now proceed to the optimization. To simplify the notation, from here on we drop the time dependency of variables. It is helpful to observe that the contested harvest may be written, using equations (1) and (2), as

$$H = R\beta(E_1 + E_2). \tag{7}$$

Substituting equations (7), (3), and (4) into (5) and (6), we obtain each group's income:

$$Y_1 = \left(\frac{\alpha_1 F_1}{\alpha_1 F_1 + \alpha_2 F_2}\right) R\beta(E_1 + E_2) \tag{8}$$

$$Y_2 = \left(\frac{\alpha_2 F_2}{\alpha_1 F_1 + \alpha_2 F_2}\right) R\beta(E_1 + E_2). \tag{9}$$

Each group maximizes its income by choosing how many people to allocate to conflict and harvesting, subject to the constraint $E_i + F_i = N_i$, where $i = \{1, 2\}$. When optimizing, the two groups are assumed to follow a Cournot-Nash-type conflict protocol.[18] Performing the optimization for group 1 yields its reaction function:

$$\frac{F_1}{F_2} = \frac{\alpha_2(E_1 + E_2)}{\alpha_1 F_1 + \alpha_2 F_2}. \tag{10}$$

Similarly, the reaction function of group 2 is given by

$$\frac{F_2}{F_1} = \frac{\alpha_1(E_1 + E_2)}{\alpha_1 F_1 + \alpha_2 F_2}. \tag{11}$$

Solving equations (10) and (11) for F_1 and F_2, we get

$$F_1 = \frac{\sqrt{\alpha_2}(N_1 + N_2)}{2\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)} \tag{12}$$

$$F_2 = \frac{\sqrt{\alpha_1}(N_1 + N_2)}{2\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)}. \tag{13}$$

17. This assumption is conceptually equivalent to assuming that each group tries to consume its own harvest but that the harvest is also subject to appropriation by the rival group.

18. That is, each group takes the effort allocation of its rival as given when choosing its own allocation.

Substituting F_1 and F_2 in equations (8) and (9), we obtain the income solutions:

$$Y_1 = \frac{\sqrt{\alpha_1}}{\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)} R\beta \frac{(N_1 + N_2)}{2} \tag{14}$$

$$Y_2 = \frac{\sqrt{\alpha_2}}{\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)} R\beta \frac{(N_1 + N_2)}{2}. \tag{15}$$

Populations grow according to the equations $\frac{dN_i}{dt} = \delta_i N_i, i = \{1, 2\}$. The population growth rates are given by $\delta_1 = \varepsilon + \phi \frac{Y_1}{N_1} + a_1(\alpha_1) F_1 + b_1(\alpha_2) F_2$ and $\delta_2 = \varepsilon + \phi \frac{Y_2}{N_2} + a_2(\alpha_2) F_2 + b_2(\alpha_1) F_1$. Incorporating δ_1 and δ_2 into the population equations of motion, we get

$$\frac{dN_1}{dt} = N_1\left(\varepsilon + \phi \frac{Y_1}{N_1} + a_1(\alpha_1)F_1 + b_1(\alpha_2)F_2\right) \tag{16}$$

$$\frac{dN_2}{dt} = N_2\left(\varepsilon + \phi \frac{Y_2}{N_2} + a_2(\alpha_2)F_2 + b_2(\alpha_1)F_1\right), \tag{17}$$

where ε denotes the difference between natural birth rate and death rate and $\phi \frac{Y_i}{N_i}$ captures the positive dependence of population growth on income per capita ($\phi > 0$).[19] We assume that $\varepsilon < 0$, implying that without the resource to consume or for sufficiently low per capita income, which is tied to the resource via equations (14) and (15), our resource-dependent populations will eventually decline to 0.[20] The negative terms a_i and b_i model the destructive effect of conflict on population: a_i grows with α_i (i.e., as group i becomes more efficient in conflict), and b_i declines with α_j ($j \neq i$) (i.e., as group j becomes more efficient in conflict).[21]

The growth rate of the resource is given by the difference between its natural growth and total harvesting. The natural growth of the resource is given by the standard logistic form inside the square brackets in equation (18).[22] Combining the logistic growth with the harvesting functions gives the following resource equation of motion:

$$\frac{dR}{dt} = \left[r^* R\left(1 - \frac{R}{K^*}\right)\right] - \beta R E_1 - \beta R E_2, \tag{18}$$

19. This assumption is used in many studies (e.g., Prskawetz, Feichtinger, and Wirl 1994; Milik and Prskawetz 1996; Brander and Taylor 1998) and is supported empirically in LDCs (Heerink 1994). In many DCs, fertility seems to decline with income. We return to this topic in section 5. An alternative interpretation, which may well also apply to DCs, is that the resource is essential for procreation (e.g., when food declines, fertility declines).

20. For a similar assumption in a model without conflict, see, for example, Brander and Taylor (1998).

21. One could assume that ε and ϕ differ across groups. This would complicate the model without adding much insight, as there is no a priori reason to assume that the rival groups differ in these respects.

22. The logistic form applies to renewable resources, which are our focus (see, e.g., Clark 1990, 10). The model can be applied to non renewable resources by setting $r^* = 0$. In this case, one may want to introduce a term for resource discovery.

where r^* is the rate of growth of the resource and K^* is the resource-carrying capacity. The parameters r^* and K^* are assumed to fall with conflict $(F_1 + F_2)$: $r^* = r + r_c(F_1 + F_2)$ and $K^* = K + K_c(F_1 + F_2)$. K and r are the intrinsic resource-carrying capacity and growth rate parameters, respectively, and r_c and K_c are negative coefficients. Noting that $E_1 = N_1 - F_1$ and $E_2 = N_2 - F_2$, equation (18) can be rewritten as follows:

$$\frac{dR}{dt} = \left[r^* R\left(1 - \frac{R}{K^*}\right)\right] - \beta R\left(\frac{N_1 + N_2}{2}\right). \tag{19}$$

Substituting equations (12), (13), (14), and (15) into (16) and (17), we get a system of three nonlinear differential equations, (16), (17), and (19) that describe the dynamics in terms of R, N_1, and N_2.

3.2 STEADY STATES

The model's steady states are found by setting the time derivatives of N_1, N_2, and R in equations (16), (17), and (19) to 0. This results in a simultaneous system of nonlinear equations.

$$N_1 = \left(\varepsilon + \phi \frac{\sqrt{\alpha_1}}{\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)} R\beta \frac{(N_1 + N_2)}{2N_1}\right) = 0 \tag{20}$$

$$N_2 = \left(\varepsilon + \phi \frac{\sqrt{\alpha_2}}{\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right)} R\beta \frac{(N_1 + N_2)}{2N_2}\right) = 0 \tag{21}$$

$$rR\left(1 - \frac{R}{K}\right) - \beta R\left(\frac{N_1 + N_2}{2}\right) = 0. \tag{22}$$

To make the analysis tractable, we have abstracted from the destructive effects of conflict on the population and resource stocks in equations (20), (21), and (22), setting a_i, b_i, r_c, and K_c to 0. We discuss the likely impacts of these destructive effects in section 5.3.

The system of equations (20), (21), and (22) has five steady-state solutions (four "corner" and one "internal").[23] Beginning with the corner solutions, the steady state with $N_1 = 0, N_2 = 0, R = 0$ depicts a situation in which both populations have declined to 0 following an exhaustion of the resource. The steady state with $N_1 = 0$, $N_2 = 0$, $R = K$ depicts a situation in which both populations have declined to 0 before the resource has been depleted. Subsequently, the resource recovers to its carrying capacity.[24] In the next two steady states, $N_1 = 0$, $N_2 = N_2^*$, and $R = R^*$ or $N_1 = N_1^*$, $N_2 = 0$, and $R = R^*$, respectively, where asterisks denote some positive level. Obviously, in these four corner steady states, there is no conflict in the system.

23. This steady state configuration is typical in the ecological competition literature (see section 2).

24. In section 5, we provide human historical examples of societies going extinct due to environmental degradation precipitated by conflict over renewable resources.

The fifth internal steady state is given by

$$N_1 = \frac{2r}{\beta}\left(\frac{2\varepsilon}{K\beta\phi}+1\right)\frac{\sqrt{\alpha_1}}{\left(\sqrt{\alpha_1}+\sqrt{\alpha_2}\right)} \tag{23}$$

$$N_2 = \frac{2r}{\beta}\left(\frac{2\varepsilon}{K\beta\phi}+1\right)\frac{\sqrt{\alpha_2}}{\left(\sqrt{\alpha_1}+\sqrt{\alpha_2}\right)} \tag{24}$$

$$R = \frac{-2\varepsilon}{\beta\phi}. \tag{25}$$

This internal steady state features conflict between the two rival groups. Using equations (12) and (13), the effort allocations for conflict and harvesting can be written as

$$F_1 = \frac{N_1}{2}\sqrt{\frac{\alpha_2}{\alpha_1}} \tag{26}$$

$$F_2 = \frac{N_2}{2}\sqrt{\frac{\alpha_1}{\alpha_2}} \tag{27}$$

$$E_1 = \frac{N_1}{2}\frac{\left(2\sqrt{\alpha_1}-\sqrt{\alpha_2}\right)}{\sqrt{\alpha_1}} \tag{28}$$

$$E_2 = \frac{N_2}{2}\frac{\left(2\sqrt{\alpha_2}-\sqrt{\alpha_1}\right)}{\sqrt{\alpha_2}}. \tag{29}$$

For the internal steady state to exist, the condition $\frac{2\varepsilon}{\beta K\phi}+1>0$ must hold. Otherwise, equation (25) implies $R>K$, and equations (23) and (24) imply $N_1<0$ and $N_2<0$. In this case, the system will collapse to one of the corner steady states.[25]

3.3 COMPARATIVE STATICS

The partial derivatives of equations (23) through (29) determine the impact of changes in the exogenous variables on the internal steady state. Equations (26) and (23) imply that in a steady state where group 2 is better at conflict (α_2 is greater), ceteris paribus, relative to a base case steady state, group 1 allocates less effort to harvesting, whereas group 2 devotes more effort to harvesting (i.e., $\frac{\partial E_1}{\partial \alpha_2}<0$ and $\frac{\partial E_2}{\partial \alpha_2}>0$). This is so because the larger is α_2, the greater is the portion of the total harvest accruing to group 2 and the smaller is the portion accruing to group 1. Thus, group 2 has a greater incentive to harvest relative to the base case, whereas group 1 has less incentive to harvest. In

25. When the groups are equal in every respect, the steady states $S=K$, $R_1=R_2=0$ or $S=0$, $R_1=R_2=0$ could also be attained. When the groups differ, the system also could collapse to one of the steady states with only one group. For that to occur, the rate of population growth of one of the groups needs always to be negative due to a too low income (e.g., because its conflict efficiency is too low).

the new steady state, group 2 then devotes less effort to conflict, whereas group 1 devotes more effort to conflict, relative to their base case steady state allocations (i.e., $\frac{\partial F_1}{\partial \alpha_2} > 0$ and $\frac{\partial F_2}{\partial \alpha_2} < 0$).

Equations (14), (15), (23), and (24) imply that a steady state featuring a greater α_2 relative to a base case, ceteris paribus, features smaller group 1 population and income and larger group 2 population and income. Hence, a group that is better at conflict is able to sustain a higher income and population. But, when its rival is relatively better at conflict, the group's population and income are lower. These results are driven by the fact that a group that is better at conflict gains more from it, raising its income and ultimately its population via the fertility function.

A steady state that features higher resource-carrying capacity (K) or intrinsic growth rate (r) relative to a base case, ceteris paribus, has a higher population (see equations [23] and [24]) and the same resource stock (see equation [25]). To gain intuition, observe from equation (19) that larger r and K imply a greater resource growth rate ($\frac{dR}{dt}$). Hence, for any harvesting level, the marginal return to harvesting tends to rise when r or K rise (see equations [1] and [2]). In turn, income also rises. Fertility then rises, which raises population levels (see equations [16] and [17]). In the new steady state, the higher population offsets the higher resource growth rate (through harvesting), which is just enough to bring back the resource stock to its base case level.

Equations (26) and (27) imply that the higher are r and K, the greater is the conflict effort. Since the steady state resource stock is unaltered by changes in r and K, the steady state marginal return to harvesting is also unaltered (see equations [1] and [2]). Hence, the allocation of effort between conflict and harvesting in a steady state with higher r and K is driven by the greater populations.

A steady state featuring a higher fertility parameter ϕ, ceteris paribus, features a lower resource stock (see equations [23], [24], [26], and [27]). Higher fertility leads to greater populations, which in turn tend to deplete the resource stock. The effect of a greater natural net death rate (ε) is naturally opposite that of a greater ϕ.

The comparative statics effect of harvesting efficiency (β) on conflict is given by

$$\frac{\partial F_i}{\partial \beta} = \frac{\sqrt{\alpha_j}}{\left(\sqrt{\alpha_1} + \sqrt{\alpha_2}\right) K \beta^3 \phi}(-4\varepsilon - K\beta\phi) \quad i, j = \{1, 2\}; i \neq j. \tag{30}$$

Thus, given a steady state with a relatively higher (lower) R, the greater is β, the higher (lower) is the steady state level of conflict.[26] From equation (25), R rises with ε and falls with β and ϕ. Hence, when death rate is high and harvesting efficiency and fertility are low, a rise in harvesting efficiency may result in more conflict.

3.4 DYNAMICS

Abstracting from the destructive effects of conflict, our dynamic system is given by

26. The sign of equation (30) is positive if in steady state $S > K/2$ and negative if $S < K/2$ (see equation [25]).

$$\frac{dN_1}{dt} = N_1\left(\varepsilon + \phi\frac{\sqrt{\alpha_1}}{\sqrt{\alpha_1}+\sqrt{\alpha_2}}\frac{N_1 + N_2}{2N_1}\right)\beta R \tag{31}$$

$$\frac{dN_2}{dt} = N_2\left(\varepsilon + \phi\frac{\sqrt{\alpha 2}}{\sqrt{\alpha_1}+\sqrt{\alpha_2}}\frac{N_1 + N_2}{2N_2}\right)\beta R$$

$$\frac{dR}{dt} = rR\left(1 - \frac{R}{K}\right) - (N_1 + N_2)\beta R.$$

To the best of our knowledge, this system of nonlinear differential equations does not have an analytical solution. Two methods are typically used in such cases to learn about the dynamics: local stability analysis and numerical simulation. We study the dynamics via simulation.[27]

To simulate the system, we need to chose a particular parameterization. There are, of course, many sets of parameters from which one could choose. It is clear that the particular outcome may apply only to the chosen set. For comparison purposes, we set α_1 and α_2 to 1, as is (implicitly) the case in Hirshleifer (1995). However, we also require population and resource parameters. To that effect, one could choose a parameterization not based on real-world records.[28] Alternatively, one could pick parameters based on real-world records. Brander and Taylor (1998), for example, studied the collapse of the Easter Island society and set their parameters accordingly. They chose a carrying capacity K = 12,000 units, a resource growth rate r = 0.04 per decade, a population natural death rate ε = –0.1 per decade, a population fertility parameter ϕ = 4, a resource-harvesting efficiency parameter β = 0.00001, an initial population = 40, and an initial resource stock = 12,000 units.

The story of Easter Island is interesting for our study because it provides a natural experiment of man-nature interaction involving conflict over resources in a system that lacks well-defined and/or enforceable property rights. We use the parameters of Brander and Taylor (1998) here and discuss the story of Easter Island in further detail in section 5.[29]

Let us focus now on the model's basic dynamics. Figure 1 presents the simulation results for group 1's population (N_1), conflict effort (F_1) the resource stock (R), and income (Y_1).[30] As shown, the system cycles toward an internal steady state. Along the dynamic path, R and Y_1 lead N_1 and F_1. Intuitively, this is so because income affects fertility, and a rise in R raises income. Note also that conflict is often at its peak when the

27. A local stability analysis involves finding the system's eigenvalues around each steady state. This method is not tractable here because the system's characteristic equation (which determines the eigenvalues) is cubic. Since the system is of order 3, the phase diagram approach also is not tractable. For studies that employ dynamic numerical simulation, see, for example, Prskawetz, Feichtinger, and Wirl (1994); Milik and Prskawetz (1996); and Brander and Taylor (1998).

28. In this case, the goal is mainly to demonstrate the mathematical properties of the dynamic system simulated, as in, for example, Prskawetz, Feichtinger, and Wirl (1994) and Milik and Prskawetz (1996).

29. As noted by Brander and Taylor (1998), the estimated initial population for the island ranges from around 20 to 100. Our simulation results are virtually the same for different initial populations within this range.

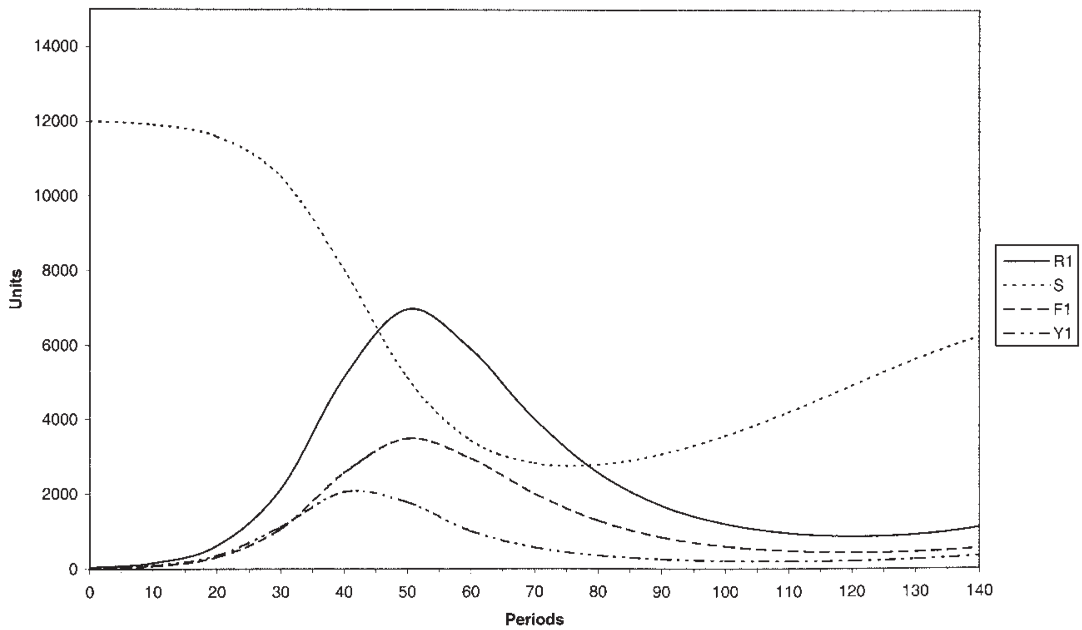

Figure 1: Conflict on Easter Island
NOTE: R_1, S, F_1 = conflict effort. Y_1 = income.

resource reaches its trough. This fact coincides with the observed tendency of resource scarcity to promote and/or intensify conflict in many less developed societies.

We conclude this section with brief report of additional simulation results. Because the general behavior of the system in these cases is similar to Figure 1, we do not graph them.[31] When group 1 is better at conflict than group 2 ($\alpha_1 = 1.25$, $\alpha_2 = 0.75$), the less conflict-effective group allocates more effort to conflict along each point of the trajectory, whereas the more conflict-effective group allocates less effort to conflict. Raising r (0.06) suppresses the fluctuations but raises conflict in the steady state. Thus, although the system becomes less vulnerable to intensive conflict, there is a steady state trade-off. A higher K (20,000) makes the system less damped and also raises conflict in the steady state. Finally, a higher β(0.001) drives the system to the steady state with $R = K$ and $N_1 = N_2 = 0$. In this case, both populations go to 0 before R is fully diminished. Consequently, the resource grows back to carrying capacity.

4. EXTENDING THE BASIC MODEL

In the basic model, the decisiveness parameter of the contest success functions was equal to unity, and the groups were equally efficient at harvesting. In this section, we relax these assumptions.

30. In this symmetric case, the values for group 2 are identical. Income is plotted at 10 times its actual level to better visualize it.

31. In each case, the parameters not mentioned are kept as in Figure 1.

4.1 CHANGES IN THE DECISIVENESS PARAMETER

As in Hirshleifer (1995), the contest success functions are now given by[32]

$$P_i(t) = \frac{F_i^m(t)}{F_1^m(t) + F_2^m(t)} \quad i = \{1, 2\}. \tag{32}$$

In equation (32), as m grows, the marginal effectiveness of group i's fighting effort in capturing a proportion of contested goods rises. As Hirshleifer noted, with low m, the defensive resources have the upper hand. Hirshleifer's main findings are that the existence of the internal equilibrium requires $m < 1$, and a rise in m (from 0 to 1) raises the equilibrium level of effort devoted to conflict. He referred to the situation with $m > 1$ as the breakdown of anarchy.

Hirshleifer (1995) assumed that the total allocated effort ($N_1 + N_2$ in our model) is open to appropriation.[33] In other studies (e.g., Hirshleifer 1989), he assumed, as we do in this study, that only the total output produced (H in our model) is open to appropriation. In Hirshleifer (1989), the equilibrium exists for any m, or anarchy never breaks. As we shall see, this result does not hold in our dynamic case. That is, we can get the breakdown of anarchy only when harvested resources are contested.

Using equation (32) and assuming that the two groups have equal harvesting efficiencies, our dynamic system may be written as

$$\begin{aligned}
\frac{dN_1}{dt} &= N_1\left(\varepsilon + \phi\tfrac{(N_1+N_2)}{2N_1(m+1)}\right)\beta R \\
\frac{dN_2}{dt} &= N_2\left(\varepsilon + \phi\tfrac{(N_1+N_2)}{2N_2(m+1)}\right)\beta R \\
\frac{dR}{dt} &= rR\left(1 - \frac{R}{K}\right) - \frac{(N_1 + N_2)}{(m+1)}\beta R.
\end{aligned} \tag{33}$$

Similar to system (31), system (33) also has four corner steady states. The fifth (internal) steady state is given by

$$\begin{aligned}
N_1 &= N_2 = r(m+1)\left(\frac{(m+1)\varepsilon}{\beta\phi K} + 1\right) \\
R &= -\frac{(m+1)\varepsilon}{\beta\phi}.
\end{aligned} \tag{34}$$

For the internal steady state to exist, the condition $\frac{(m+1)\varepsilon}{\beta K\phi} + 1 > 0$ must hold. In contrast to Hirshleifer (1995), $m > 1$ need not ensure the breakdown of anarchy (recall that

32. To make the analysis tractable and focus attention on m, we assume $\alpha_1 = \alpha_2 = 1$ and keep our earlier assumption regarding the nondestructive aspects of conflict, both of which are as in Hirshleifer (1995).

33. This assumption would imply in our model that human beings can be forced to fight against their own group or harvest for the other group, both of which we find unappealing.

$\varepsilon < 0$). Our breakdown of anarchy condition also depends on resource and population parameters. In addition to large m, inefficient harvesting, low fertility, a high death rate, and a low carrying capacity all lead to the breakdown of anarchy via system collapse.

We now examine the impact of m, assuming anarchy does not break. The comparative statics of population with respect to m in equation (34) are ambiguous, ceteris paribus. Since the optimal allocation of effort for conflict is given by $F_1 = F_2 = (\frac{m}{m+1})(\frac{N_1+N_2}{2})$, the comparative statics of conflict allocations also are ambiguous, which is a markedly different result from Hirshleifer (1995). In that study, a rise in m raises the conflict allocation. In our study, the effect of m on conflict is ambiguous, depending on the population and resource parameters. We may gain insight by inspecting the effect of m on the relative conflict allocation $(\frac{F_1}{N_1}) = \frac{m}{m+1}$. This ratio is growing with m as in Hirshleifer. However, since N_1 and N_2 are exogenous in Hirshleifer, that model does not exhibit the ambiguity of our dynamic case, where N_1 and N_2 are endogenous.

The dynamic system (33) is structurally similar to system (31). The only differences are the replacement of $\sqrt{\alpha_i}/(\sqrt{\alpha_1} + \sqrt{\alpha_2})$ in the first two differential equations by $1/(m + 1)$ and the introduction of $1/(m + 1)$ in the third differential equation. Thus, the dynamics of the two systems will be qualitatively similar.

4.2 DIFFERENCES IN HARVESTING EFFICIENCY

In section 3.1, we saw that raising the conflict efficiency of a group relative to its rival raises its income and lowers the effort it devotes to conflict. Since total effort is devoted to conflict or harvesting, a natural question to ask is, what happens when the harvesting efficiency of one group is raised relative to its rival? To answer this question, we rework the basic model under the assumption of differences in harvesting efficiency.

Letting β_i denote the harvesting efficiency of group i, the internal steady state is given by

$$N_1 = 2r\left(\frac{\sqrt{\alpha_1\beta_2}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right)\left(1+\frac{2\varepsilon}{K\phi}\left(\frac{\sqrt{\alpha_1\beta_2}+\sqrt{\alpha_2\beta_1}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right)\right) \tag{35}$$

$$N_2 = 2r\left(\frac{\sqrt{\alpha_1\beta_2}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right)\left(1+\frac{2\varepsilon}{K\phi}\left(\frac{\sqrt{\alpha_1\beta_2}+\sqrt{\alpha_2\beta_1}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right)\right)$$

$$R = \frac{-2\varepsilon}{\phi}\left(\frac{\sqrt{\alpha_1\beta_2}+\sqrt{\alpha_2\beta_1}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right).$$

The study state conflict efforts are[34]

34. It is worth noting that the term in square brackets in equations (36) and (37) equals unity when $\beta_1 = \beta_2$, and we then recover equations (26) and (27). Similarly, equation (35) collapses to equations (23), (24), and (25), respectively, under the same condition.

$$F_1 = \left(\frac{N_1}{2}\right)\sqrt{\frac{\alpha_2}{\alpha_1}}\left[\frac{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}{\beta_1\sqrt{\alpha_2\beta_2}+\beta_2\sqrt{\alpha_1\beta_1}}\right], \tag{36}$$

$$F_2 = \left(\frac{N_2}{2}\right)\sqrt{\frac{\alpha_1}{\alpha_2}}\left[\frac{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}{\beta_1\sqrt{\alpha_2\beta_2}+\beta_2\sqrt{\alpha_1\beta_1}}\right]. \tag{37}$$

Next, we study the comparative statics effects of β_1 and β_2 on conflict. It is clear from equations (36) and (37) that the effects of β_1 and β_2 on conflict depend on their effects on N_1 and N_2. To examine these impacts, we rewrite the first level in equation (35) as

$$N_1 = 2r\left(\left[\frac{\sqrt{\alpha_1\beta_2}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}}\right]+\frac{2\varepsilon}{K\phi}\left[\frac{\sqrt{\alpha_1\beta_2}+\sqrt{\alpha_1\alpha_2\beta_1\beta_2}}{\beta_1\sqrt{\alpha_1\beta_2}+\beta_2\sqrt{\alpha_2\beta_1}^{\,2}}\right]\right). \tag{38}$$

Each of the expressions written in square brackets in equation (38) is decreasing in β_1 and β_2. Recalling that $\varepsilon < 0$, we see that the impact of an increase in β_1 or β_2 on N_1 is ambiguous. The same is true for N_2. It follows from equations (36) and (37) that the effect of changes in the harvesting efficiencies on F_1 and F_2 also are ambiguous. These results are similar to those we derived in the basic model and occur for the same reason: specifically, they are driven by the size of the resource stock. When the resource stock is high, increases in the harvesting efficiency raises conflict. The opposite will be true when the resource stock is low.

5. IMPLICATIONS FOR HISTORICAL AND CONTEMPORARY CONFLICT

In our simulation, we have employed parameters for the historical society of Easter Island. In Figure 1, the society exhibited a brief flowering and then declined to a dismal state with low population, resources, and income. In this section, we compare our results with historical accounts of Easter Island. Scholars such as Tainter (1988), Ponting (1991), and Bahn and Flenley (1992) have argued that Easter Island is just one of several examples of historical societal collapse precipitated by conflict over degrading resources. Following our discussion of Easter Island, we discuss other societies that experienced a similar history. These scholars and others argue that contemporary societies face similar risks (although possibly of a weaker strength), particularly in LDCs, where societies are closely dependent on the natural environment. We end this section with a discussion of our model's implications for LDCs.

5.1 EASTER ISLAND

Many years ago, abundant forests and a society thrived on Easter Island. By the time Europeans arrived on the island in the early 18th century, they found land without trees and a small population living in poverty and conflict. Many scholars have puzzled over this story. Recently, several studies have explained the collapse by thinking about the island in the spirit of Malthus ([1798] 1970). That is, the human population overexploited the island's resources, leading to its own decline.[35] Brander and Taylor (1998) have modeled the Malthusian interpretation of the Easter Island story while ignoring conflict over resources. Our model offers the possibility to investigate the history of Easter Island based on the assumption that there was conflict over natural resources on the island.

The foundation of our model captures the general setting of the Easter Island society. A considerable literature argues there was ample conflict over natural resources between well-organized clans on Easter Island (e.g., see Ponting 1991; Keegan 1993; and Lee 2000). As noted by Ponting (1991), the clans were each led by a dominant chief, supporting our modeling of groups as unitary actors.[36] Naturally, conflict in primitive societies such as Easter Island was labor intensive, as we have assumed. Our simplifying assumption that conflict does not kill people or damage the resource is appropriate for Easter Island. Anthropologists who have studied ancient Easter Island skulls found evidence of injuries but not of life-threatening injuries, indicating conflict but not fatal wounds. The loser in the conflict often lost his *property* but not his life (Lee 2000).[37] Also, it is likely that Easter Island's society did not develop efficient property rights institutions.[38] As noted by Brander and Taylor (1998), the assumptions that population rises with income and actors maximize current incomes are reasonable for Easter Island, which was a primitive society.

Turning to the simulation, period 0 in Figure 1 corresponds to the years from A.D. 400 to 700, which is the time range in which settlers are said to have arrived on Easter Island.[39] Conflict intensifies harvesting in the beginning of the simulation. The population then rises, and the resource declines. As a result, the population also declines. The population peaks at 14,000 around period 50 and declines to around 2,000 around period 130 (year 1700). In Brander and Taylor's (1998) study, population peaks at around 10,000 people 25 periods later and then declines to 3,800 around period 130. In our study, the resource reaches a minimum of around 3,000 units around period 80, whereas in Brander and Taylor's study it reaches a minimum of around 5,000 units 25 periods later.[40]

35. See, for example, Ponting (1991), Bahn and Flenley (1992), Van Tilberg (1994), Gowdy (1998), Brander and Taylor (1998), Brown and Flavin (1999), and Reuveny and Decker (2000).

36. Extending our model to include more than two clans does not require changing its structure but will make it less tractable.

37. Conflict of this type also is sometimes observed in other primitive societies. For example, see Keegan's (1993) account of the African Zulus.

38. See Ponting (1991), Van Tilberg (1994), Brander and Taylor (1998), and Luterbacher (2001). It is suggested that the islanders did not develop efficient institutions to deal with the degradation and, because the island's trees grew slowly, people did not grasp the nature of the slow change taking place.

39. The date the island was first settled varies across studies. Brander and Taylor (1998), for example, used the date A.D. 400; Gowdy (1998) and Bahn and Flenley (1992) used A.D. 700; and Brown and Flavin (1999) used A.D. 500.

40. The model becomes less applicable in the early 1800s, when the island is no longer a closed system.

It is hard to compare the resource in the model to the real world. Because both our model and Brander and Taylor's (1998) are stylized, the resource represents an ecological complex consisting of soil, fish species, forestry, water, and so on. Nonetheless, we can discuss the population trajectory. The available information on Easter Island is based on archeological inquiries. The estimated maximum population ranges from 7,000 to 20,000, whereas the timing of this maximum is in the range of A.D. 1100 to 1500.[41] When Easter Island was discovered in the 18th century, the Dutch admiral Rogeveen estimated there were 3,000 people on the island, and the British captain Cook estimated there were 2,000 people.

Based purely on simulation results, the model of Brander and Taylor (1998) is plausible. However, their model does not include conflict on Easter Island, which is well documented in the literature. Our simulation results suggest that the inclusion of conflict is consistent with historical and anthropological accounts of the island's society. Thus, our model also is a plausible description of the main social forces operating on Easter Island.

5.2 OTHER HISTORICAL SOCIETIES

Although the story of Easter Island is likely the most famous, several examples of societal collapse precipitated by conflict over degrading renewable resources exist. Weiskel (1989, 104) noted that each of these societies exhibited "gradual emergence, brief flowering and rapid collapse of civilization," accompanied by conflicts driven by the desire to control arable land or other essential renewable resources. In this section, we briefly discuss the cases of the Sumerian and the Mayan civilizations.[42]

The Sumerian society, which arose in the fertile valley of the twin rivers Tigris and Euphrates, is generally accepted as the world's first literate society, having attained this status by about 3000 B.C. The society was made up of a number of cities that were often in conflict over the land separating them. The land was valuable because of the innovation of irrigation. With irrigation, the Sumerian society moved from subsistence farming to cash crops and traded within the society and with non-Sumerians for metals and manufactured goods.

Because of the ability to create wealth through cash crops, the Sumerians began to overexploit the land via almost constant irrigation. Traditional agricultural techniques such as crop shifting and allowing lands to lie fallow were abandoned. The constant irrigation eventually led to a complete salinization of a vast majority of the croplands. The early stages of decline saw the loss of cash crops, which weakened the society materially, whereas later stages saw the loss of essential harvests. The Sumerian society experienced increases in the death rate, conflict over resources, and a decline in income and fertility. In a weakened state, the society was conquered in 2370 B.C. by the Akkadian empire.

41. See Ponting (1991), Bahn and Flenley (1992), Van Tilberg (1994), and Brander and Taylor (1998).

42. Our discussion of the Sumerian and Mayan cultures is based on Ponting (1991), and our discussion of the Zulu culture is based on Keegan (1993). Interested readers are directed to these sources for further details of the rise and fall of these societies and others that met a similar fate.

The story of the Sumerians illustrates one implication of our model: advancements in production (in this case irrigation) need not improve the long-term prospects of a society. Although there is little doubt that irrigation increased the short-term wealth of the Sumerians, this wealth allowed the population to grow, which in turn led to the overexploitation of the resource and conflict over the degraded resource base.

The Mayan story provides yet another example of the forces we model. Early theories of the Mayan society, which dates from 2500 B.C. and was located in southern-North and Central America, were at odds with our model. Historians once thought that this great civilization was peaceful. The Mayans were thought to have practiced environmentally friendly agricultural techniques. As a result of this thinking, historians were at a loss to explain the collapse of the Mayan civilization. Much like Easter Island, the civilization went into decline long before European contact. When the "lost cities" (so named because the ancient pyramid temples were lost to the encroaching jungle, having been abandoned for generations) were discovered by American archeologists in the late 1830s, descendants of the Maya had no knowledge of them.

Subsequent research of the Mayan culture has changed scholarly thinking. Mainly due to the translation of the Mayan script, historians now know that, far from being a peaceful culture, the Mayan society was composed of cities that were almost continually in conflict over arable land. As with the Sumerians, Mayan land increased in value as agricultural innovation allowed the society to move beyond the subsistence level. As with Easter Island, a major factor in the Mayan decline appears to have been deforestation and subsequent soil erosion, which occurred as large amounts of land were cleared for agricultural purposes.

5.3 CONTEMPORARY LDCs

Although we believe our model captures the underlying tendencies inherent in many LDCs, the model's implications should be considered carefully. This is true because of the potentially mitigating effects that nonresource-based sectors, demographic transition, property rights institutions, foreign aid and trade, and technological innovation might have on resource-dependent societies, none of which are included in our model. As noted by Reuveny and Decker (2000), although these effects may not have been significant on Easter Island, they could be significant in LDCs.

Dependence on the environment for livelihood is more prevalent in LDCs than in DCs. The buildup of nonresource-based sectors might alleviate the pressures that LDCs place on natural resources. However, since this is a costly and lengthy process, conflict similar to what we have modeled may be plausible for some LDCs in the future, and, as noted, according to some scholars it is already beginning to emerge.

Our model ignores the theory of demographic transition. According to this theory, when income per capita is low, population growth rises with income. As income per capita rises above some threshold, population growth declines with income (Heerink 1994). This theory is not without critics, but it is accepted by many scholars.[43] Demographic transition implies that economic growth may mitigate pressures on the envi-

43. For critics, see, for example, Abernethy (1993) and Dilworth (1994).

ronment in LDCs. However, this approach also entails a cost. Economic growth increases pollution, resource depletion, and often results in deforestation. Moreover, several authors also argue that the biosphere cannot sustain the DCs' current per capita income for all countries.[44]

Similar to all Hirshleifer-type models, this study assumes the absence of a well-developed and enforced system of property rights. With such institutions in place, the model's basic structure becomes less applicable as a basis for analysis. However, property rights institutions are generally defined and enforced less rigorously in LDCs than in DCs.[45] This does not mean that efficient institutions cannot arise in LDCs. Ostrom (1990) observed cases in which such institutions arose in poor societies as well as cases in which they did not. Hence, the emergence of efficient property rights institutions in LDCs cannot be taken for granted and may require intervention from DCs or international organizations.

We have also ignored the role of foreign aid and trade. Of course, resource scarcity may be alleviated by foreign aid. However, we believe our simple model may be of value in gaining insight into the underlying tendencies of the system without aid. As for trade, if a natural-resource-dependent economy has a comparative advantage in a nonresource-based sector, trade prompts the allocation of more labor to this sector, reducing harvesting and raising social welfare. However, LDCs typically have comparative advantage in their resource-based sectors. In this case, trade stimulates resource harvesting. Over time, the resource gets overexploited, and social welfare declines relative to autarky.[46] Consequently, the rising resource scarcity may induce conflict along lines suggested in the introduction.

The model has a Malthusian spirit. The typical argument made against the Malthusian prediction is that it does not consider technological innovation. As argued by Homer-Dixon (1999), conflict may reduce society's ability to innovate to begin with.[47] Ignoring this point for the moment, in our setup innovation could, for example, raise the harvesting efficiency, carrying capacity, and resource growth rate and reduce the death rate. According to our model, raising the resource growth or carrying capacity would not have made societies less conflictive. Additionally, a rise in harvesting efficiency and a reduction in the death rate might lead to systemic collapse. In other words, technological innovation may not be the panacea to Malthusian conflict. At the same time, conflicts over natural resources are currently more frequent and intense in LDCs than in DCs. Hence, it is possible that once resources become plentiful, actors' behavior changes so that conflict is no longer considered a rational option to begin with.

44. See Cohen (1995) for a detailed review of many studies demonstrating this claim.

45. In fact, according to the 2001 Heritage Foundation's Index of Economic Freedom (www.heritage.org/index/), none of the 17 countries we have mentioned in the introduction as experiencing resource conflicts are ranked in the top 30 worldwide with regard to property rights, and only 1 country (Turkey) is ranked in the top 50. Out of the 17, the majority are LDCs. We would like to thank an anonymous reviewer for bringing up this point.

46. Bee (1987), Brown (1995), and Brander and Taylor (1997) have provided empirical examples of the detrimental effect of international trade on resource-dependent economies.

47. This point is controversial. For example, Simon (1996) and Boserup (1981) have argued that these same adverse forces generate more innovation since necessity is the mother of invention.

Finally, in the analytical solution to our model we have abstracted from the potentially destructive effects of conflict on the population and resource base. Some conflicts over resources in LDCs are not intense enough to significantly affect the resource base or the overall death rate. In terms of our model, relatively low-intensity, scarcity-induced conflicts could be, and some say already are, a steady state outcome in LDCs. However, some conflicts in Africa, for example, are said to have already registered a negative effect on population forecasts and the environment. In extreme cases, aided by technological innovation in fighting, the effect of conflict could be so destructive as to eventually drive the system into one of its corner steady states.

6. CONCLUSIONS

We have developed a dynamic model of conflict based on Hirshleifer's (1989) initial static, game-theoretic framework. To our knowledge, this is the first model in the economic literature on conflict that makes Hirshleifer's framework dynamic. We have employed the model to study conflict over renewable resources in historical and present-day less developed societies.

Our model has five steady states. Four steady states exhibit no conflict because either one or both groups are extinct. The condition for the breakdown of anarchy in our model is more complicated than in Hirshleifer (1995). In our case, the breakdown depends on parameters of the resource and population, not only on the decisiveness parameter. We focused on a fifth steady state that features conflict. The comparative statics reveal that changes enhancing the resource stock or the population raise conflict. A rise in the conflict efficiency of one group relative to the other raises the group's income and reduces its conflict effort. A rise in the model's decisiveness parameter generates an ambiguous effect on conflict, which also differs from Hirshleifer's static model. Finally, the effect of raising harvesting efficiency on conflict is positive when the resource stock is high.

Turning to the dynamics, our results generally accord with the stories of historical societies that exhibited a relatively brief flowering, followed by decay, all the while exhibiting conflict over the resource base. Finally, we have discussed the model's implications for contemporary LDCs, paying particular attention to the limitations resulting from our modeling approach.

We have employed a relatively simple framework. Several research extensions, therefore, are worth pursuing. For example, the agents in the model maximize their current incomes. Although we find this assumption appropriate in our case, it would be interesting to introduce foresight into the model. Second, given our focus on less developed societies, we ignored demographic transition. Incorporating demographic transition into the model is an interesting extension. It would also be interesting to add more goods and factors of production. These features are expected to remove pressure from the resource, but we believe that the resource-population fluctuations will not disappear in their presence. Third, in the solution, we have ignored the destructive effects of conflict. It would be interesting, although mathematically complicated, to relax this assumption. However, as long as the destructive effects of conflict are not so strong as to result in system collapse, we suspect that this extension would not change the nature of our findings.

In the end, although the model's trajectory is consistent with the spirit of the history of several ancient societies, contemporary LDCs differ, of course, from these cases. That said, we believe our findings serve as a warning of what the future might look like should societies choose to fight over renewable resources instead of devising the appropriate institutions to control their exploitation.

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