Resource Scarcity and Conflict: An Economic Analysis.

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Abstract

As time passes renewable resource scarcities are becoming more common throughout the world. There is increasing evidence that these scarcities are a causal factor in civil unrest and violent conflict. We present a simple model of renewable resource dynamics, population dynamics and conflict. Conflict is triggered by per capita resource scarcity. We examine the role and nature of conflict on the bioeconomic system. We find that conflict is Nature’s way of protecting vital renewable resources from human exploitation. Conflict, as modeled, increases the death rate of the human population, damages the resource, and diverts resources away from harvesting natural the resource. These effects speed the return to a peaceful steady state. On the policy front we find that commonly advocated policies such as technical innovation which enhance resource growth or the system resources carrying capacity are dangerous in that they heighten system vulnerability to conflict. Birth control, however, is found to be a stabilizing factor which reduce the likelihood of conflict.
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Resource Scarcity and Conflict: An Economic Analysis.

Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetic ratio.

By the law of our nature which makes food necessary to the life of man, the effects of these two unequal powers must be kept equal.

— Thomas Malthus (1798)

1 Introduction

According to the World Resources Institute, by the year 2050 the world’s human population is likely to exceed nine billion. At the same time, economic industrial output will probably quadruple. These developments will no doubt put huge demands on renewable resources. Environmental decay in various forms such as air and water pollution, reduction in the quality and size of underground water reservoirs, dying lakes, shrinking forests, decline in the amount and quality of agricultural and grazing land, dwindling fish grounds, depletion of the ozone layer, and global warming are already observed today. As pointed out by several analysts, as a result of the global trends of rising population and economic industrial output, environmental decay and depletion of renewable resources will probably become more widespread and severe in the future.

What is likely to be the effect of environmental decay on the social fabric planet Earth? Logically, there could be two answers. A pessimist would argue that environmental scarcity will increase tension and generate conflict among and within societies. An optimist, on the other hand, would argue that faced with such threats to their common existence, humans will find ways to cooperate to overcome them.

Malthus (1798) was one of the first writers who investigated the links between socio-economic and environmental change. As our opening quotation indicates, Malthus assumed that unconstrained population growth was geometrical while food production could only grow arithmetically. The perception that Malthus predicted the eventual collapse of our ecosystem is widespread, but wrong. Malthus recognized that there must naturally be curbs on human population growth. According to Malthus, most of these curbs involved misery and vice and the burden of these curbs would fall heavily on poor nations and on the under-classes of

1 For a full projection see World Resources (1986, 1992).
2 See, for instance, Westing (1986) and Homer-Dixon (1994).
3 For an optimist view see, for instance, Simon (1981, 1989).
society. Conflict, in the form of political unrest and outright war, was recognized by Malthus as the most severe of all vices. As environmental scarcity becomes ever more visible, Malthus’ words seem hauntingly correct, and, we feel, deserve more attention.

Adopting the Malthusian approach, of course, begs an immediate question. To what extent are environmental scarcity and conflict associated empirically? While our data on these links are generally limited, the empirical literature on these links is (unfortunately) growing. Starting in the early 1990s, systematic evidence on the links between renewable resource depletion and conflict is being collected by the Peace and Science program at the University of Toronto, Canada and the American Academy of Art and science in Cambridge, Massachusetts. In general, environmental scarcities are found to be a systematic source of conflict. Thus far, the most violent consequences of these effects have taken place in the Third World where human dependence on the natural environment is higher than in industrialized nations. As time passes, however, developed countries may face similar problems as they are generally running ecological deficits with the rest of the world.

Yet, the focus of the existing literature has been on investigating cases in which conflict is caused by environmental degradation. What happens to the social-economic system once conflict erupts and how does the system evolve over time since then is not studied. Important questions are not addressed. How likely is it that conflict will erupt? If it does, how long will it last? What are the factors that determine the length of such violence? While human history teaches us that wars do not last forever, most past major wars were not directly caused by environmental degradation. Will conflict due to environmental scarcity come to an end at some point in time? If it does end, are additional environmental conflicts possible? What are the long term consequences of violence due to environmental degradation? These questions are at the center of our paper.

Our approach is deductive. Assuming that environmental degeneration leads to conflict, we develop a dynamic model in which the stock of renewable resources and the size of the human population are both endogenous. Adopting a ‘strong sustainability’ view as in Rees (1997), renewable resources are assumed to affect procreation. Assuming the existence of a certain exogenous threshold of small resource per capita beyond which violence erupts, we investigate the evolution the resource stock and population size over time. Conflict is

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4 For an overview of this program see Homer-Dixon (1994) and Homer-Dixon and Percival (1996).
5 On these deficits, see Rees (1997).
modeled to have three impacts. First, it diverts labor away from normal economic activities into war-making or domestic unrest related activities. Second, it increases the death rate. Last, it damages the resource stock.

Our results can be summarized as follows. First, conflict due to environmental scarcity can not be a steady state of the system. Second, conflict serves to bring the system back to a peaceful path. Ironically, then, conflict serves as a harsh defense mechanism, ensuring the survival of at least some of the human species. Third, peace could be a steady state, where by population and resource stock settle at certain safe equilibrium levels that assure no future conflict. Fourth, once the system is shocked away from equilibrium, we identify the conditions under which the dynamic path of the system involves conflict, as well as the time length of staying in the conflict zone. Fifth, we are also able to show that the system has bad equilibria which involve zero population. In one equilibrium the resource is depleted, while in the other it is at its maximum level.

The remainder of our paper is organized as follows. Section 2 discusses several theoretical links from environmental scarcity to conflict. Section 3 reviews the empirical literature on these links. Section 4 constructs a formal model to investigate the effect of conflict on the bio-economic system. Section 5 analyzes the steady state of the model. Section 6 deals with the model’s transition path once the system is shocked. Finally, section 7 offers concluding remarks and highlights research extensions.

2 Conflict and the environment

Environmental degradation does not receive much attention by international conflict scholars. Recently, however, several studies identified theoretical channels through which environmental decay may cause conflict. To be sure, there are also studies which doubt the importance of these channels.\(^6\) While this debate is not our main focus, we certainly belong to the first camp. In this section we Ørst deØne the concept of environmental conflict, which we term Malthusian. Next, we discuss theoretical channels from environmental degradation to conflict.

In broad terms, there are two deØnitions of environmental conflict in the literature. According to Libiszewski (1992), for instance, environmental conflict is caused by human actions

\(^6\) See Deudney (1990), and Molvaer (1991).
which disturb the regeneration of renewable resources. Westings (1991) enlarges this definition to include non-renewable resources whose usage causes an environmental decay. We emphasize the former definition. In our view this definition is broader since regardless of human actions, nonrenewable resources will eventually deplete, in which case their effect becomes a non issue. In contrast, the salience of human interaction with the natural environment is not likely to decrease in the foreseeable future. The links from environmental degradation to conflict could be classified in four types: (1) economic decline and dwindling of resources per capita; (2) population migration or displacement; (3) social problems aggravated by environmental scarcities; and, (4) disrupted institutions and the rule of law.

The problems associated with economic decline per capita include factors such as a decrease in the quantity or quality of agricultural goods and animals, insufficient supplies of crucial goods such as water and timber, and environmentally induced health problems due to air and water pollution or toxic waste. These effects may generate conflict by creating tensions over such questions as who will bear their cost, who will alleviate their effect, who contributed the most to produce them, and who will get a bigger share of what is already a shrinking pie of resources per capita.

The second link from environmental scarcity to conflict involves the migration or forced displacement of populations. As the resources in one region deplete or deteriorate, some of the region’s population may migrate or may be displaced by other groups as the resource base of the land dwindles. If the destination land is already occupied, the newly arrived population may increase the pressures on its resource base. As immigrants and natives meet, they may clash over many issues, including ethnic and cultural differences, upsetting of labor markets due to excess supply or competition over better jobs, and competition over the strained resources of the new land.

The third channel which links environmental scarcity to conflict places the above channels in a context of an unstable domestic or international political foundation. For instance, if the land includes historically rival groups, the probability of conflict due to environmental scarcity

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7 If nonrenewable resources adversely affect renewable resources, they become as important for our purpose and could be thought of as another cause of degradation.
9 See Falkenmark (1986) and Wallenstein (1986) on conflict because of dwindling water resources and drops in food supply, respectively.
increases as the relations of such groups may be already strained over past issues. In general, then, environmental degradation may exacerbate existing cleavages and/or conflicts. 11

The fourth link from environmental degradation to conflict involves the weakening of institutions and the decrease in the efficacy of rule of law. This may happen in several ways. First, environmental degradation may erode the people’s confidence in their government. In severe cases people may attempt to overthrow the current regime. Second, it may encourage people to strike or not pay taxes, acts which may further weaken the government. Third, it may reduce the willingness to undertake investments in economic and social infrastructure. Again, this may further elevate the sense of deprivation and weaken the rule of law. Last, environmental degeneration may embroil countries in conflicts over dwindling resources, possibly along lines dividing North and South, thus putting international order at risk. 12

3 Empirical evidence and implications

Our main intention in this section is to demonstrate that environmental scarcities are already causing political conflicts. Given space limitations, our review is not intended to be exhaustive. For comprehensive reviews of empirical cases we refer readers to Westing (1986), Moss (1993), and Homer-Dixon (1994, 1996).

Most studies in the empirical literature on conflict and environmental scarcity employ a case study research design. One exception is the study of Choucri and North (1975). These authors estimate a simultaneous equation model from land size, population, military expenditures, trade, and industrial output. Their findings point out that in the late nineteenth and early twentieth centuries, population growth in Europe was associated with increased competition over colonial lands producing raw materials, agricultural foodstuff, and animal products. The competition increased the incentives to maintain large armies, heightened arms races, and thus could be considered as an indirect cause of World War I.

Next, we turn to several case studies. Mackey (1981) finds that food and crops scarcities played a role in instigating domestic violence in fifteenth century Spain. Ehrlich et. al. (1977) and Durham (1979) argue that agricultural land scarcities coupled with rising population caused migration from El Salvador to Honduras. As land was also relatively scarce in

11 On the consequences of scarcity for ethnic and class cleavages see Gurr (1985).
12 The North-South argument is discussed in Ophuls (1977).
Honduras, the competition between the two populations led to the 1969 Soccer-War. Homer-Dixon (1991) supports these claims when he notes that in the 1950s and 1960s renewable resources per capita in El Salvador declined rapidly following large losses of Virgin forest and land erosion. Analyzing the post World War II Philippines, Porter and Ganapin (1988) and Hawes (1990) find that internal strife is linked to deforestation and land degradation. Coupled with a high population growth, these changes led to large domestic population displacements which triggered civil descent aimed at the central government. Along similar lines, Goldman (1991) argues that in Eastern Europe and the former Soviet Republics, degradations in the quantity and quality of agricultural land, forests, and water, and excessive air pollution generated anti-Russian sentiments which contributed to the breakup of the Soviet Empire.

Homer-Dixon (1994) provides additional evidence on cases in which scarcities of renewable resources led to conflict. Since the mid-1970s, population growth and land exploitation in Bangladesh significantly cut the amount of cropland per capita and cause population migration to India. The migration is a source of ethnic conflict (the Bengali immigrants from Bangladesh are Muslim while Indians are predominantly Hindu). Other disputes over renewable resources include the 1972-1973 English-Icelandic Cod War, the clash between Mauritania and Senegal over the waters of the Senegal river, domestic violence in South Africa, water and agricultural land shortages in the Middle East, water conflicts between South Africa and Lesotho, and Egypt and Ethiopia, and the recent conflicts over fishery rights between Canada and the U.S., and Canada and Spain. Evidence that environmental scarcities weaken institutions is presented in the cases of the Luminoso rebellion in Peru, and the fall of the Baby Doc Duvalier’s regime in Haiti. Last, some researchers argue that demographic pressures accompanied by shortages of renewable resources are creating pressures in China that may lead to the country’s fragmentation.

In sum, several studies present evidence pointing out that environmental scarcity can lead to violent international or domestic conflict. Yet, these studies do not investigate the interplay between conflict and the economic-environmental system. Admitting that these processes are extremely non linear and complicated, studies focus on the mechanisms leading from environmental change to conflict. We start our analysis where those studies stop.

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13 Most notably, in 1983 almost 2000 Bengalese were masquerade by natives who accused them of stealing the best land (Homer-Dixon, 1994:22). See also Ashok (1996b).
14 The Middle water disputes were studied by many researchers. See, for instance, Lowi (1993).
Beginning from some steady state, we shock the system and investigate its dynamic path. If conflict erupts, we investigate what happens to the system over time. In particular, we investigate if the system will return to a peaceful equilibrium, what will determine the length of conflict, and how does the answer to these questions varies with the parameters of the economy and the environment.

4 Renewable resources and conflict

Our model extends the work of Brander and Taylor (forthcoming), Clark (1990), and Schaefer (1957) to include the possibility of political and/or violent conflict. Following the empirical observations made by Homer-Dixon (1994), violent conflict and/or political unrest arises when per capita resources reach a minimum critical level. We characterize this type of conflict as Malthusian. We use the model to examine the role and nature of conflict on the stability of the bioeconomic system, and the impact of various policies on the likelihood and duration of conflict.

4.1 The model

The model features a population of $L(t)$ individuals at time $t$, which is assume to equal the labor force. Each individual has preferences over a harvested renewable resource good $h$ and a composite good $c$ given by

$$u = h^\beta c^{1-\beta}; 0 < \beta < 1$$

The harvested good is assumed to be essential for procreation. We see this in equation (14) below which shows that the period $t$ fertility rate is increase in the level of per capita resources. Thus the harvested good ($h$) may be thought of as food, or as the compilation of resources that are necessary for the production of food, such as water, air and land. The composite good ($c$), may be thought of as a composite of all other goods. Each individual in the population is assume to be endowed with one labor unit, which may be split between the harvesting activity and the production of the composite good. Individuals will allocate their labor unit between harvesting and production. Letting $L_H(t)$ denote the total amount of labor devoted to harvesting, and $L_C(t)$ denote the amount of labor devoted to production of the composite good we obtain:
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\[ L(t) = L_H(t) + L_C(t), \]  
\[ \gamma L(t) = L_H(t) + L_C(t). \]  
\[ \gamma L(t) = L_H(t) + L_C(t), \]  
\[ \gamma L(t) = L_H(t) + L_C(t). \]

during any period in which there is no conflict. One impact that conflict has is that it diverts resources away from production and harvesting; resources are spent on such activities as waring, or protesting during times of domestic unrest. To capture this idea, we assume that during any period featuring conflict, the total amount of labor devoted to production or harvesting is \( \gamma L(t) \) where \( \gamma \in (0, 1] \). The smaller is \( \gamma \) the greater is the intensity of conflict. \[16\]

\[ \gamma L(t) = L_H(t) + L_C(t). \]

We treat the composite good as the numeraire good and assume that it is produced competitively according to a constant returns to scale technology, with labor as the only input. Given preferences (1), the composite good will always be in demand in equilibrium. Since its price is normalized to 1, this will be the equilibrium wage in the production sector. We assume that labor moves freely between the two sectors of the economy. As such, the wage in the harvesting sector will also be 1.

We denote the stock of the resource good in period \( t \) by \( S(t) \). The harvesting production function is given by

\[ H^S(t) = \alpha S(t)L_H(t), \]

where \( H^S(t) \) denoted the harvest supply. We assume competition in the harvesting sector which leads to the following zero profit condition

\[ pH^S(t) - wL_H(t) = 0. \]

Thus, substituting (4) into (5), and using the fact that the competitive wage must equal 1 we obtain the equilibrium price of the harvested good:

\[ p = \frac{1}{\alpha S(t)}. \]

\[16\] Depending on how one deones the bioeconomic system modelled here, this conflict may be thought of as purely domestic or as international. That latter would be the case if nations went to war over natural resources. We have outlined such cases in section 3.
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Each individual is endowed with one labor unit, however a portion of the unit \((1 - \gamma)\) is diverted from productive uses due to conflict. Thus, the budget constraint facing each agent is\(^{17}\)

\[
ph + c = \gamma. \tag{7}
\]

Maximizing (1) subject to the budget constraint (7) yields the optimal individual demands. Aggregating over the population yields the following demand functions for the harvested and manufactured goods.

\[
H^D(t) = \frac{\beta \gamma L(t)}{p} \quad \text{and} \quad C^D(t) = \gamma (1 - \beta) L(t). \tag{8}
\]

Substituting (6) into (8) we find that the equilibrium level of harvested resource is given by

\[
H(t) = \beta L(t) \gamma \alpha S(t). \tag{9}
\]

From equation (4), \(L_H = H^S / (\alpha S(t))\). Using the equilibrium condition in the market for harvested good we see that

\[
L_H(t) = \frac{L(t) \beta \gamma}{p \alpha S(t)} = \gamma \beta L(t) \tag{10}
\]

Substituting (10) into (3), and noting that the production technology of the composite good is \(C(t) = L_C(t)\) we see that

\[
\gamma L(t) = L(t) \beta \gamma + C(t) \tag{11}
\]

so

\[
C(t) = (1 - \beta) \gamma L(t). \tag{12}
\]

Equations (9) and (12) give the period \(t\) equilibrium levels of the harvested resource and the composite good. The levels of these goods are dependent on the resources stock and the population level. We now introduce the dynamic paths of the population and resource stocks.

\(^{17}\)Alternatively one could assume that \((1 - \gamma) L\) individuals engage fully in conflict while the remainder work full time, and transfer some of their wealth to support those individuals engaged in conflict. The assumption embodied in (7) seems more realistic if when one assumes political unrest rather than full scale war.
4.2 Population and resource dynamics

The assumed population dynamics are governed by the following differential equation

\[
\frac{dL(t)}{dt} = L(t) \left[ b - \eta d + F(t) \right]
\]  

where \( F(t) = \phi H(t)/L(t) \)  

represents the period \( t \) fertility rate. The parameter \( b \) represents the natural birth rate, and \( d \) the natural death rate. The parameter \( \eta \geq 1 \) represents direct impact of conflict on population. The more violent is conflict the greater will be the death rate during any period of conflict. In peaceful times \( \eta = 1 \), by assumption. \(^{18}\) Using (9), the fertility rate may be rewritten as

\[
F(t) = \phi \beta \alpha \gamma S(t).
\]

Note that as the as the resource stock falls harvesting becomes more difficult and renewable resource per capita falls, negatively impacting fertility. Substituting (15) into (13) we obtain

\[
\frac{dL(t)}{dt} = L(t) \left[ b - \eta d + \phi \beta \alpha \gamma S(t) \right].
\]

The assumed dynamics of the resource stock are governed by the following differential equation

\[
\frac{dS(t)}{dt} = (1 - \theta) \left[ rS(t) \left(1 - \frac{S(t)}{K}\right) \right] - H(t),
\]

where \( r \) denotes the intrinsic rate of growth of the resource, and \( K \) denotes the carrying capacity of the resource. The term in square brackets on the right hand side of (17) represents the period \( t \) natural growth rate of the resource, which is assumed to follow the familiar logistic form. Without harvesting growth will be rapid if the current stock is far from its carrying capacity, however, as this capacity is approached growth will slow and eventually cease. The overall period \( t \) change in the resource stock is the difference between its growth rate and the harvest rate, \( H(t) \).

\(^{18}\)We assume that \( d > b \), which implies that the population will decline to zero for sufficiently low rates of fertility.
The parameter $\theta$ captures the possible impact that conflict may have on the growth rate of the renewable resource. Specifically, we assume that conflict slows this growth rate. This may occur because of destruction of the resource itself or damage to inputs that allow the resource to grow. It is worth noting that if $\theta = 1$ growth will be halted. Using (9) to substitute for the harvest rate in (17) we obtain

$$\frac{dS(t)}{dt} = (1 - \theta) \left[ r S(t) \left( 1 - \frac{S(t)}{K} \right) \right] - \beta \gamma L(t) \alpha S(t). \quad (18)$$

Conflict will alter the values of $\theta$ and $\gamma$ in (18). The direct impact of $\theta$ (increasing from zero), on $S(t)$, is negative. The direct impact of the diversion of harvesting resources (a drop in $\gamma$ from 1), on $S(t)$, is positive.

Equations (16) and (18) describe the model’s dynamics. We have described the direct effects of conflict on the resource stock and population level. However, by observing (16) we see that population is affected by the stock of resources (via fertility), and from (18) we see that, in turn, population affects the resource stock (via harvesting). Thus there is a complex dynamic interaction between population and the resource stock. Consequently, conflict will have indirect as well as direct effects on population and the stock of resources. To examine all of these effects we need to examine the nature of the system’s dynamics.

4.3 A discussion of system dynamics

As we show in section 5, the system has two stable steady states, one characterized by peace and the other by conflict. The dynamic behavior around these steady states can be cyclical. This means that when the system is shocked, both population level and the resource stock will fluctuate around the steady state before returning to it. These cycles are illustrated in Panel 2a of Figure 2 below for the ratio of the resource stock to the population level. Two interior steady states exist, one exhibiting peace and the other exhibiting Malthusian conflict. We shall assume an initial steady state exhibits peace. This level is illustrated by the upper line in Panel 2a. As the system is shocked away from this steady state, the resulting fluctuations in population and the resource stock may bring the system into what we call a conflict zone. This zone is characterized by low levels of per capita resources.

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19 These shocks can be both positive or negative. By positive we mean a shock that raises the per capita level of the resource stock. Thus examples of a positive shock include unusually good weather, or the introduction of a more hearty crop. A negative shock is one that decreases the per capita level of the resource stock.
i.e., \( S(t)/L(t) < \bar{V} \), where \( \bar{V} \) is an exogenous constant. In Panel 2a \( \bar{V} = 1 \). In the peace zone \((S(t)/L(t) > \bar{V})\) system dynamics will be governed by peace time variables, that is where \( \gamma = 1, \theta = 0, \) and \( \eta = 1 \). When the system crosses into the conflict zone dynamics will change as \( \gamma < 1, \theta > 0, \) and \( \eta > 1 \). At the point of transition, the initial conditions of the system change, ensuring a smooth transition across the conflict threshold.

After entry into the conflict zone the paths of the population and resource stock tend toward the steady state described by war. However, as we show in section 5 below, this conflict steady state is located further into the peace zone than is the peace time steady state. That is it is located above the upper line in Panel 2a. Thus we know that in approaching its war time steady state, the system will once again cross over the conflict threshold. At this time initial conditions and dynamics will change, once again being governed by peace time variables. Since time has passed however, we show that the new dynamics in the peace zone are more damped than before. The conflict zone could be crossed several times during this adjustment, but we show that the peace time interior steady state will eventually be reached.

In the subsequent sections we analyze the model’s steady states and dynamics in detail. In doing so we are able to develop several policy implications, and answer questions such as what variables serve to increase or decrease conflict likelihood and length, and the degree of resource scarcity.

5 The steady states

This section we analyze the existence of various steady states in the model and the dynamics around these steady states. Several of these steady states exhibit a population level of zero, and are unstable. We focus on the model’s stable steady states. These steady states feature positive levels of both population and resource stock. We refer to these as interior steady states.

The system described by the differential equations (16) and (18) has three types of steady state equilibria. Two of these equilibria types feature a population level of zero. In the first

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Example of negative shocks are bad weather, or the influx of population from outside the bioeconomic region under study. Panel 2a illustrates the impact of a small negative shock.
of these equilibria types the steady state resource stock is also zero, and in the second it is equal to its carrying capacity $K$. These two equilibria follow directly from observation of (16) and (18). The third type of steady state exhibits a positive level of population and resource stock. We describe this interior equilibrium solution in detail in the following proposition.

Proposition 1 The bioeconomic system described by equations (16) and (18) exhibits an interior steady state equilibrium solution where \( \tilde{L} = \left( \frac{r(1-\theta)}{\alpha \beta \phi} \right) \left( 1 - \frac{\eta d - b}{\phi \alpha \beta \gamma K} \right) \) and \( \tilde{S} = \frac{\eta d - b}{\phi \alpha \beta \gamma} \); \( \eta d > b \).

Proof. The solution is derived directly from solving (16) and (18), and will be an interior solution as long as \( 0 < \tilde{S} < K \). That is, as long as \( 0 < \frac{\eta d - b}{\phi \alpha \beta \gamma} < K \). If this condition is violated the system will collapse either to the steady state \( \tilde{S} = K, \tilde{L} = 0 \), or to the steady state \( \tilde{S} = 0, \tilde{L} = 0 \). Q.E.D.

The dynamics of the system are governed by the pair of non-linear differential equations (16) and (18). These equation do not have an analytical solution. To analyze the system dynamics we examine the first order Taylor series approximation around the steady state \( \tilde{L}, \tilde{S} \):

\[
\begin{bmatrix}
\frac{dL(t)}{dt} \\
\frac{dS(t)}{dt}
\end{bmatrix} = \begin{bmatrix}
b - \eta d + \phi \alpha \beta \gamma \tilde{S} & \tilde{L} \alpha \beta \phi \\
-\alpha \beta \gamma \tilde{S} & (1 - \theta) r \left( 1 - \frac{2 \tilde{S}}{K} \right) - \alpha \beta \gamma \tilde{L}
\end{bmatrix} \begin{bmatrix}
(L(t) - \tilde{L}) \\
(S(t) - \tilde{S})
\end{bmatrix}
\]

(19)

The general solution to this system is given by the equation

\[
\begin{bmatrix}
\frac{dL(t)}{dt} \\
\frac{dS(t)}{dt}
\end{bmatrix} = c_1 E_1 e^{\lambda_1 t} + c_2 E_2 e^{\lambda_2 t}
\]

(20)

where \( c_1 \) and \( c_2 \) are positive constants determined by initial conditions, \( \lambda_1 \) and \( \lambda_2 \) are the eigenvalues of coefficient matrix in (19), and \( E_1 \) and \( E_2 \) are the corresponding eigenvectors.\(^{21}\)

The eigenvalues of the matrix in (19) are the roots of equation (21), where \( \text{det}(A) \) denoted the determinant of the matrix \( A \).

\(^{20}\)The reader will observe that these conditions describe two steady states. The first under peace, where \( \gamma = 1, \theta = 0, \) and \( \eta = 1 \). The second under Malthusian conflict where \( \gamma < 1, \theta > 0, \) and \( \eta > 1 \).

\(^{21}\)For details on the solutions of the system of linear differential equations see Boyce and DiPrema (1992).
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The corresponding eigen vectors satisfy

\[
\begin{bmatrix}
 b - \eta d + \phi \alpha \beta \gamma \tilde{S} - \lambda_i & \tilde{L} \alpha \beta \phi \\
-\alpha \beta \gamma \tilde{S} & (1 - \theta) r \left( 1 - \frac{S}{K} \right) - \alpha \beta \gamma \tilde{L} - \lambda_i
\end{bmatrix}
\begin{bmatrix}
 E_1 \\
 E_2
\end{bmatrix}
= 0; \quad i = \{1, 2\}. \quad (22)
\]

Solving (21) to obtain the eigenvalues for each steady state, we will be able to investigate dynamic changes around the steady state using (20). This may be seen by examining each steady state in turn.

**Steady State 1: \((\tilde{L} = 0, \tilde{S} = 0)\)**

Substituting the steady state value of population and the resource stock into (21) it is easy to see that the eigenvalues are \(\lambda_1 = b - \eta d\) and \(\lambda_2 = (1 - \theta) r\). Since one root, \(\lambda_2\), is positive and the other, \(\lambda_1\), is negative this steady state is an unstable saddle point.

**Steady State 2: \((\tilde{L} = 0, \tilde{S} = K)\)**

The eigenvalues corresponding to this steady state are \(\lambda_1 = b - \eta d + \phi \alpha \beta \gamma K\) and \(\lambda_2 = -(1 - \theta) r\). Since \(\frac{\eta d - b}{\phi \alpha \beta \gamma} < K\) we see that \(\lambda_1\) is positive, and since \(\lambda_2\) is negative we see that this steady state is also an unstable saddle point.

The fact that both steady states 1 and 2 are unstable saddle points means that starting from either of these steady states any shock will result in a dynamic path upon which neither \(S\) nor \(L\) will converge back to these steady state values. In fact these paths will eventually lead to the interior steady state described below.

**Steady State 3. \((\tilde{L} = \left( \frac{r(1-\theta)}{\phi \alpha \beta \gamma} \right) \left( 1 - \left( \frac{\eta d - b}{\phi \alpha \beta \gamma R} \right) \right), \tilde{S} = \frac{\eta d - b}{\phi \alpha \beta \gamma} \)**

The eigenvalues for this steady state are the roots of the following equation

\[
\det\begin{pmatrix}
-\lambda & r \left( 1 - \theta \right) \left( 1 - \frac{S}{K} \right) \frac{\phi}{\gamma} \\
\frac{(b - \eta d)}{\phi} & -r \left( 1 - \theta \right) \frac{S}{K} - \lambda
\end{pmatrix}
= 0 \quad (23)
\]
That is

\[ \lambda_1 = \frac{1}{2} \left[ -r (1 - \theta) \frac{\bar{S}}{K} + \sqrt{\left[ r (1 - \theta) \frac{\bar{S}}{K} \right]^2 - 4[r (1 - \theta)] \left( 1 - \frac{\bar{S}}{K} \right) \left( \frac{D - b}{\gamma} \right)} \right] \]

and

\[ \lambda_2 = \frac{1}{2} \left[ -r (1 - \theta) \frac{\bar{S}}{K} - \sqrt{\left[ r (1 - \theta) \frac{\bar{S}}{K} \right]^2 - 4[r (1 - \theta)] \left( 1 - \frac{\bar{S}}{K} \right) \left( \frac{D - b}{\gamma} \right)} \right] \]

If the discriminant \( \left[ r (1 - \theta) \frac{\bar{S}}{K} \right]^2 - 4[r (1 - \theta)] \left( 1 - \frac{\bar{S}}{K} \right) \left( \frac{D - b}{\gamma} \right) > 0 \) then both roots in (21) will be negative, and steady state 3 will be approached monotonically.

If the discriminant is negative then the eigenvalues occur in complex conjugate pairs, each containing a real and an imaginary part. That is, if \( \lambda_1 = \omega + i\mu \), then \( \lambda_2 = \omega - i\mu \). Furthermore the corresponding eigenvectors also occur as complex conjugates. That is, if \( E_1 = a + ib \), then \( E_2 = a - ib \).\(^2\) The real and imaginary parts of the eigenvalues are given by

\[ \omega = \frac{1}{2} \left[ -r (1 - \theta) \frac{\bar{S}}{K} \right], \tag{24} \]

and

\[ \mu = \frac{1}{2} \left[ -r (1 - \theta) \frac{\bar{S}}{K} \right] - 4[r (1 - \theta)] \left( 1 - \frac{\bar{S}}{K} \right) \left( \frac{D - b}{\gamma} \right). \tag{25} \]

Note that since \( \omega < 0 \), steady state 3 is a stable point both when the discriminant is positive and when it is negative.

6 The system under peace and conflict

6.1 The steady state and conflict.

As discussed in sections 1 through 3, the link between resource scarcity and the rise of political unrest and violent conflict dates back to Malthus (1798), and has been documented

\(^2\)Note bold faced characters denote \( 2 \times 1 \) vectors.
recently by several researchers. Recall our assumption that Malthusian conflict arises whenever \( S(t)/L(t) < \bar{V} \).

We first investigate the impacts of conflict on the interior steady state.

Proposition 2 The interior steady state under assumed conflict conditions (i.e., \( \gamma < 1 \), \( \eta > 1 \), \( \theta < 1 \)), will exhibit a higher resource stock than the non-conflict steady state. The steady state population level will be lower in the conflict steady state than in the non-conflict steady state as long as the resource stock is sufficiently high.

Proof. The proof follows directly from differentiation of the steady state conditions. We first examine the impact of an increase in the death rate

\[
\frac{\partial \bar{S}}{\partial \eta} = \frac{d}{\phi \alpha \beta \gamma} > 0, \text{ and } \frac{\partial \bar{L}}{\partial \eta} = -\left( \frac{r(1-\theta)}{\alpha \beta \gamma} \right) \left( \frac{d}{\phi \alpha \beta \gamma K} \right) < 0
\]

A reduction the rate of growth of the resource, \( \theta \), is examined next. This has no impact on the interior steady state level of resources. This reduction will slow the system’s recovery to the steady state however as long as growth is not totally stalled the resource will recover. The steady state population will decline, however, because the harvest rate must fall in response to the slowed growth of the resource. This in turn reduces the fertility rate.

\[
\frac{\partial \bar{S}}{\partial \theta} = 0, \text{ and } \frac{\partial \bar{L}}{\partial \theta} = -\left( \frac{r(1-\theta)}{\alpha \beta \gamma} \right) \left( 1 - \left( \frac{\eta d - b}{\phi \alpha \beta \gamma K} \right) \right) < 0
\]

The impact of the diversion of labor resources (a decrease in \( \gamma \)) clearly raises the resource stock as harvesting falls. The impact on the population level is less clear cut.

\[
\frac{\partial \bar{S}}{\partial \gamma} = -\frac{(\eta d - b)}{\phi \alpha \beta \gamma^2} = -\frac{\bar{S}}{\gamma}, \text{ and, } \frac{\partial \bar{L}}{\partial \gamma} = -\frac{r(1-\theta)}{\alpha \beta \gamma^2} + \frac{2r \bar{S}}{\alpha \beta \gamma^2 K}.
\]

The ambiguous outcome on population arises because the per capita harvest rate is impacted directly through the diversion of resources and indirectly through the level of the resource stock. The former lowers the harvest rate and lowers fertility. The latter may or may not raise the harvest rate as implied by the logistic form of resource growth. If the resource stock is low (relative to its carrying capacity \( \frac{S}{K} < \frac{1}{2} \)) the diversion of labor resources will raise the stock of the resource and in so doing will rise the rate of resource growth, raising the harvest rate and fertility, raising the steady state population level. If the resource stock is high relative to its carrying capacity, the diversion of labor resources will again raise the

\[23\text{Note that if the destruction of resources are total (} \theta = 1 \text{) the system will collapse to the steady state quilibrium characterized by } \bar{S} = 0, \bar{L} = 0.\]
resource stock, but the result will be a lower rate of growth of the resource. Thus the harvest rate will decline and this will negatively impact the population level via fertility. Q.E.D.

Any peace time steady state equilibrium must satisfy $\tilde{S}/\tilde{L} > \tilde{V}$. This condition implies

$$\frac{d-b}{\phi \alpha \beta} \left( \frac{r}{\alpha \beta} \left( 1 - \left( \frac{d-b}{\phi \alpha \beta K} \right) \right) \right) = \frac{d-b}{\phi \alpha \beta} \left( 1 - \frac{d-b}{\phi \alpha \beta K} \right) > \tilde{V}. \quad (26)$$

This condition leads directly to the following proposition.

Proposition 3  Malthusian conflict cannot last forever.

Proof. The interior steady state condition featuring conflict is characterized by the following condition

$$\frac{\eta d-b}{\phi \alpha \beta \gamma} \left( \frac{r(1-\theta)}{\alpha \beta \gamma} \left( 1 - \left( \frac{\eta d-b}{\phi \alpha \beta \gamma K} \right) \right) \right) = \frac{\eta d-b}{\phi \alpha \beta \gamma} \left( 1 - \frac{\eta d-b}{\phi \alpha \beta \gamma K} \right), \quad (27)$$

However, given that $\eta \geq 1$, $\gamma \leq 1$, and $\theta \in [0, 1)$ it follows that

$$\frac{\eta d-b}{\phi \alpha \beta \gamma} \left( 1 - \frac{\eta d-b}{\phi \alpha \beta \gamma K} \right) \geq \frac{d-b}{\phi \alpha \beta \gamma} \left( 1 - \frac{d-b}{\phi \alpha \beta \gamma K} \right) > \tilde{V} \quad (28)$$

which violates the conflict condition that $\tilde{S}/\tilde{L} < \tilde{V}$. Q.E.D.

Note that proposition 3 does not imply that conflict cannot arise in the model. It simply implies that conflict cannot last forever. Once the system is shocked from the peace time steady state, it may cross the threshold into the conflict zone. At this point the system aims at returning to the steady state characterized by conflict, but in doing so we know that the conflict zone will be exited and peace time dynamics will take over. Hence conflict cannot last forever. This result accords with casual real world observation. While conflicts vary in their severity and duration, and while tensions may seem to exist forever conflict spells are finite.

6.2 The likelihood of immediate and delayed conflict

We focus next on the vulnerability of the system to conflict. The system can enter the conflict zone either immediately (due to a large negative shock), or in a delayed manner (due to the
resulting cyclical fluctuations about the steady state). The likelihood of immediate entry is falling in the distance between the peace time steady state and the conflict zone. The likelihood of delayed entry is influenced by the volatility of system dynamics.

Consider the case of immediate conflict. Imagine an exogenous population influx or an exogenous depletion of resources. The larger are these types of negative shocks the greater will be the likelihood of immediate conflict. However, as the following proposition points out, certain model parameters increase the vulnerability of the system to these negative shocks.

Proposition 4 For a given positive shock to population, or negative shock to the stock of resources. The likelihood that the shock will result in immediate Malthusian conflict is increasing in fertility ($\phi$), the intrinsic growth rate ($r$), harvesting innovation ($\alpha$), the preference for the resource good ($\beta$), and the carrying capacity of the system ($K$), and falling in the net death rate ($d - b$).

Proof. The proof follows directly from differentiation of the per capital resource stock in the peacetime steady state. That is

$$\bar{S} = \frac{d - b}{\phi r (1 - \frac{d - b}{\phi \alpha \beta K})}. \tag{29}$$

Differentiation of (29) yields the following:

$$\frac{\partial (\bar{S}/\bar{L})}{\partial \phi} < 0, \quad \frac{\partial (\bar{S}/\bar{L})}{\partial r} < 0, \quad \frac{\partial (\bar{S}/\bar{L})}{\partial \alpha} < 0, \quad \frac{\partial (\bar{S}/\bar{L})}{\partial \beta} < 0, \quad \frac{\partial (\bar{S}/\bar{L})}{\partial K} < 0, \quad \frac{\partial (\bar{S}/\bar{L})}{\partial (d - b)} > 0. \tag{30}$$

As the steady state per capita resource stock falls it becomes closer to $\bar{V}$. Q.E.D.

The policy implications arising from proposition 4 are clear, and in some cases troublesome. Birth control (decreasing $\phi$) works to decrease system vulnerability to immediate Malthusian conflict, while technological innovations that increase resource growth ($r$), carrying capacity ($K$), and harvesting efficiency ($\alpha$), and preference for the resource good ($\beta$), all work to increase the system’s vulnerability to Malthusian conflict. The results concerning resource growth and carrying capacity are particularly troublesome. Raising resource growth and carrying capacity are often advocated as solutions to the problem of resource scarcity. Indeed, if the resource was not harvested these policies would raise the resource stock, but this tells only half of the story. Increasing $r$ and/or $K$ will increase the growth rate of the resource stock, this makes harvesting easier and more resources will be devote to harvesting.
This, in turn, raises the harvest and thus the fertility rate and ultimately the population level. The net result of these policies is to lower steady state per capita resources contributing to system vulnerability to immediate Malthusian conflict.

We now examine system vulnerability to delayed Malthusian conflict. As the system is shocked away from its steady state, stability ensures that the system will follow a path back to it. As discussed in section 5.1 above, this path may lead the system into the conflict zone. That is, $S(t)/L(t)$ may fall below $\bar{V}$ even as $\bar{S}/\bar{L}$ exceeds it. To examine this type of delayed Malthusian conflict we must study the system’s dynamics.

We focus on the interior steady state, and assume that the conditions ensuring cyclic dynamic behavior about the steady state are met. That is, we assume the discriminant 

$$
\left[ r \left( 1 - \theta \right) \frac{\bar{S}}{\bar{K}} \right]^2 - 4 \left[ r \left( 1 - \theta \right) \right] \left( 1 - \frac{\bar{S}}{\bar{K}} \right) \left( \frac{\bar{d} - \bar{b}}{\bar{r}} \right)
$$

is negative. In this case system dynamics about the steady state are described by the following system of equations.

$$
\begin{bmatrix}
L(t) \\
S(t)
\end{bmatrix}
= \begin{bmatrix}
\bar{L} \\
\bar{S}
\end{bmatrix} + c_1 e^{\omega t} \begin{bmatrix}
a_1 \\
a_2
\end{bmatrix} \cos \mu t - \begin{bmatrix}
b_1 \\
b_2
\end{bmatrix} \sin \mu t +
\begin{bmatrix}
a_1 \\
a_2
\end{bmatrix} c_2 e^{\omega t} \left( \begin{bmatrix}
a_1 \\
a_2
\end{bmatrix} \cos \mu t + \begin{bmatrix}
b_1 \\
b_2
\end{bmatrix} \sin \mu t \right)
$$

where $c_1$ and $c_2$ are arbitrary constants determined by initial conditions. Given (24) and (25) it follows that the convergence to steady state 3 will involve damped oscillations of population and the resource stock about their respective steady state levels. These oscillations are illustrated in Figure 1 below.

Now assume a positive shock to the peace time steady state. That is, the stock of resources is augmented, perhaps due to the introduction of a more hearty crop. As discussed, Malthusian conflict will arise in the model whenever the line $S/L = \bar{V}$ is crossed. The likelihood and duration of conflict are affected by the following variables. First the size of the shock. The greater is the shock to the system, ceteris paribus, the greater is both the likelihood of entering into conflict and the duration of conflict. Second, the distance between the steady state and the conflict ray $S/L = \bar{V}$. This distance depends on the model’s parameters, and has been examined (in terms of immediate conflict) in proposition 4. Third, the amplitude of
the resource stock and population level dynamics. Finally the frequency of those dynamics. These latter two parameters determine tightness of the dynamics around the steady state. The dampening of amplitude reduces the number of cycles it takes for the system to return to the peacetime steady state, while the frequency determines the duration of any cycle.

Using (31) we see that the amplitude oscillations about the steady state is determined by \( \omega \), while the frequency of these oscillations is determined by \( \mu \). The impact of changes in \( \omega \) and \( \mu \) on resource stock dynamics are illustrated in Figure 1 below. Each panel in Figure 1 illustrates the dynamic path of resource stock as it is shocked away from its steady state value. Panel 1a illustrates a benchmark case. In panel 1b illustrates that the impact of an increase in \( |\omega| \) is a dampening of the fluctuation of the stock as it returns to its steady state. Panel 1c illustrates the impact of an increase in \( \mu \), namely an increase in the frequency of the oscillations about the steady state.

Panel 1a. Benchmark Case Panel 1b. High \( |\omega| \) Panel 1c. High \( \mu \)

Figure 1 (y-axis: \( S(t) \) x-axis: time \( t \) )

We examine the relationship between system dynamics and the likelihood of conflict by examining the behavior of the ratio \( \frac{S(t)}{L(t)} \) around the steady state. This ratio, along with the impact of changes in \( \omega \) and \( \mu \) are illustrated in the following Figure.

\(^{24}\text{Recall that } \omega \text{ is negative.}\)
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Panel 2a: Benchmark Case

Panel 2b: Large $\omega$

Panel 2c: Large $\mu$

Figure 2 (y-axis: $S(t)/L(t)$  x-axis: time  $\bar{V} = 1$  $\tilde{S}/\tilde{L} = 7/5$)

In Figure 2 the conflict threshold $\bar{V}$ is set to unity. Comparing panels 2b and 2c to the benchmark case in 2a we discern that the impacts of changes in $\omega$ and $\mu$ on the per capita resource stock are much the same as their impacts on resources and population individually.
Since both $S(t)$ and $L(t)$ fluctuate with frequency $\frac{\mu}{2\pi}$, their ratio will fluctuate with the same frequency. As each series is damped, bringing both the peaks and the troughs of each series closer to their steady state values, so will be their ratio. Notice that the increase in the frequency of oscillations reduces the duration of each conflict phase (the time spent below the conflict line, $\bar{V} = 1$), but tends to increase the number times the system enters (and exits) the conflict zone.

Before mapping the impact of the model’s parameters on $\omega$ and $\mu$, and thus ultimately to the system’s dynamics, it is important to note that the dynamics above and below the conflict line will differ. These differences are not illustrated in Figure 2. The reason is that the parameters $\gamma$, $\eta$, and $\theta$ impact system dynamics. As the system crosses the conflict threshold, $\gamma$ will fall (a diversion of harvesting resources to conflict activities), $\eta$ may rise (an increase in the death rate), and $\theta$ may rise (limiting the growth of the resource). Whether the latter two effects change will depend on the severity of the resulting conflict. This change in frequency and amplitude will impact both the duration and severity of resource scarcity. Since system dynamics in the conflict zone are still governed by (31), and the conflict steady state is located further into the peace zone (see proposition 3) we know that the system must recross the conflict threshold. 25

In order to study the impact of system dynamics on the likelihood of conflict we first note that entry into the conflict zone occurs from a peace zone. 26 System dynamics in the peace zone are affected by the following two parameters

$$|\omega_p| = \frac{1}{2} \left( \frac{r (d-b)}{\phi \alpha \beta K} \right)$$

(32)

and

$$\mu_p = \frac{1}{2} \sqrt{\left[ \frac{r (d-b)}{\phi \alpha \beta K} \right]^2 - 4r \left( 1 - \frac{(d-b)}{\phi \alpha \beta K} \right) (d-b)}$$

(33)

From Figure 2 we can see that the parameter which governs the likelihood of entry into the conflict phase is $|\omega_p|$. The larger is this parameter, the less likely is it that conflict will arise

25Note that each time the system reaches the conflict threshold, the initial conditions governing the path of the system are reset to the corresponding point of entry or exit from the conflict zone. This ensures continuity of the systems dynamics as it crosses the threshold.

26The obvious exception being the case where the shock is large enough to throw the system immediately into the conflict phase.
since oscillations in both the resource stock and population level are lower. Linking this parameter to the model’s underlying parameters brings about the following proposition.

Proposition 5  The likelihood of delayed Malthusian conflict is falling in the intrinsic growth rate \( r \), and net death rate \( d − b \) and rising in the fertility rate \( φ \), the efficiency of harvesting \( α \), the preference for the harvested good \( β \), and the system’s carrying capacity \( K \), ceteris paribus.

Proof. The proposition follows directly from differentiation of (32) with respect to each of the parameters of the proposition. Q.E.D.

It is instructive to compare the policy implications of propositions 5 and 4. Both propositions illustrate that an increase in the efficiency of harvesting \( α \) and an increase in the carrying capacity of the system \( K \) serves to raise the likelihood of Malthusian conflict. At the same time both propositions show that a reduction in the fertility rate \( φ \), and the preference for the harvested good \( β \) will lower the likelihood of conflict. It is only an increase in the growth rate of the resource \( r \) that has a dierential impact on the likelihood of instantaneous conflict and delayed conflict. While an increase in the growth rate of the resource pushes the peace time steady state closer to the conflict zone, it also serves to dampen oscillations about the steady state. The difference arises from the fact that a change in the growth rate of the resource does not aect it steady state level. The reason is the harvest rate adjust to in response. This increase in the harvest rate, however, does impact the steady state population through fertility (see (14)).

The conflict phase is described by per capita resource scarcity. Observation of Figure 2 illustrates that the resource scarcity is at its worst when the cycle reaches its trough. The depth of these troughs during the conflict phase are inversely proportional to the following parameter

\[ |ω_c| = \frac{1}{2} \left( \frac{r \left(1 − \theta\right) \left(ηd − b\right)}{φαβγK} \right). \]  \hspace{1cm} (34)

As this parameter rises oscillations in the conflict zone of both S and L are damped, limiting the extent of resource scarcity. One can observe this in panel 2b above.

Proposition 6  The extent of per capita resource scarcity during any conflict phase is rising in the fertility rate \( φ \), harvesting efficiency \( α \), preference for the resource good \( β \), employment \( γ \), and carrying capacity \( K \), and falling in resource growth \( r \left(1 − \theta\right) \), and the net death rate \( ηd − b \), ceteris paribus.
Proof. The proof follows directly from differentiation of (34) the parameters of the proposition. Q.E.D.

The policy implications for various parameters of proposition 6 are the same as those for proposition 5. It is interesting to examine the implications of our conflict parameters $\gamma$, $\eta$, and $\theta$, on the extent of resource scarcity. We have seen that an increase in the net death rate $(d - b)$ and the resource growth rate $(r)$ serves to dampen oscillation. An increase in the death rate due to conflict $(\eta)$ will reduce the severity of resource scarcity. A reduction in the growth rate (an increase in $\theta$) of the resource due to conflict will heighten the extent of resource scarcity. The diversion of labor resources from harvesting to conflict activities (a decrease in $\gamma$) serves to decrease the severity of per capita resource scarcity. This diversion of labor resources not only works to raise the overall growth rate of the resource stock, but also lowers the fertility rate (both due to the reduction of the level of the harvested good).

Panels 2a–2c illustrate the possibility cycling in and out of conflict phases. Thus another natural question to ask regarding the peace time phase is how long will intervals be between periods of conflict. This question implicitly addresses the frequency of the cycles during the peacetime phase. We present a detailed discussion of the frequency of the system during the conflict phase below. Since this analysis includes all relevant parameters governing the frequency of peacetime cycles. We will return to this question after we study the frequency of cycles during the conflict phase.

The duration of the conflict phase is governed by the frequency of the cycle in the conflict phase, and is in fact inversely proportional to it. The frequency is determined by the following parameter

$$
\mu_c = \frac{1}{2} \sqrt{\frac{r \left(1 - \theta\right) \eta d - b \gamma}{\phi \alpha \beta \gamma K} - 4[r \left(1 - \theta\right)\left(1 - \frac{\eta d - b}{\phi \alpha} \gamma K\right)\left(\frac{\eta d - b}{\gamma}\right)]}. \tag{35}
$$

Since we are examining system dynamics where the discriminant is negative we rewrite it as

$$
\Gamma = -\left[\frac{\nu}{\delta \gamma K}\right]^2 + 4\nu \left(1 - \frac{\nu}{\delta \gamma K}\right)\left(\frac{\nu}{\gamma}\right), \tag{36}
$$

where

\(^{27}\)Once again we caution the reader that Figure 2 illustrates equivalent dynamics above and below the conflict line. In reality these dynamics will differ see our discussion above.
Resource Scarcity and Conflict: An Economic Analysis.

\[
\begin{align*}
  r (1 - \theta) & \equiv \nu \\
  \eta d - b & \equiv \omega \\
  \phi \alpha \beta & \equiv \delta
\end{align*}
\]

Since changes in \( \mu_c \) are proportional to changes in \( \Gamma \), the expression (36) leads directly to the following proposition.

**Proposition 7** For sufficiently large carrying capacity, the duration of any conflict phase is falling in the level of carrying capacity \( (K) \), the intrinsic growth rate \( (r) \), the net death rate \( (\eta d - b) \), the fertility rate \( (\phi) \), the efficiency of harvesting \( (\alpha) \), the preference for the renewable resource \( (\beta) \), the diversion of resources from harvesting \( (\gamma) \) falls, and rising in the reduction in the rate of growth due to conflict \( (\theta) \) rises from 0, ceteris paribus.

Proof. The proof follows directly from the following derivatives of \( \Gamma \)

\[
\begin{align*}
  \frac{d\Gamma}{dK} & = 2\nu^2 \frac{\omega^2}{\delta^2 \gamma^2 K^3} + 4\nu \frac{\omega^2}{\delta^2 \gamma^2 K^2} > 0 \\
  \frac{d\Gamma}{d\nu} & = 2\omega \frac{-\nu \omega + 2\delta^2 K^2 \gamma - 2\delta K \omega}{\delta^2 \gamma^2 K^2} > 0 \quad \text{if} \quad K > \frac{1}{4\delta^2 \gamma} \left( 2\delta \omega + 2\sqrt{\left( \delta^2 \omega^2 + 2\delta^2 \gamma \omega \right)} \right) \\
  \frac{d\Gamma}{d\omega} & = 2\nu \frac{-\nu \omega - 2\delta K \omega + 2\delta^2 K^2 \gamma}{\delta^2 \gamma^2 K^2} > 0 \quad \text{if} \quad K > \frac{1}{4\delta^2 \gamma} \left( 4\delta \omega - 2\sqrt{\left( 4\delta^2 \omega^2 + 2\delta^2 \gamma \omega \right)} \right) \\
  \frac{d\Gamma}{d\delta} & = 2\nu \frac{\omega + 2\delta K}{\delta^2 \gamma^2 K^2} > 0 \\
  \frac{d\Gamma}{d\gamma} & = -2\nu \omega \frac{-\nu \omega - 4\delta K \omega + 2\delta^2 K^2 \gamma}{\delta^2 \gamma^2 K^2} < 0 \quad \text{if} \quad K > \frac{1}{4\delta^2 \gamma} \left( 4\delta \omega - 2\sqrt{\left( 4\delta^2 \omega^2 + 2\delta^2 \gamma \omega \right)} \right)
\end{align*}
\]

and the relations (37). Q.E.D.

Proposition 7 indicates that two of the three conflict variables \( (\gamma \text{ and } \eta) \) serve to speed the system out of the conflict zone. Thus, we see that conflict can be Nature’s way of protecting against resource scarcity. Both the rise in the death rate and the decline in harvesting resources bring the system toward the non conflict steady state. This protective mechanism may fail however if violence takes the form of directly destroying the resource, or otherwise limiting its growth \( (\theta) \).

Proposition 7 also has implications for policies such as lowering fertility rates and raising the efficiency of harvesting and carrying capacity. Comparing propositions 5 and 7 we see that
policies that make the system more vulnerable to delayed conflict also shorten the duration of conflict, while those that make the system less vulnerable to delayed conflict lengthen it, should it occur. This contradiction is somewhat misleading however. As one may observe from comparing Panels a and c of Figure 2, increasing the frequency of the system (and thus shortening any conflict phase), will increase the likelihood of repeated reentry into conflict. Thus each conflict phase is shortened but the total amount of time spent in conflict over, as the system returns to the steady state may well be longer as the system exhibit more episodes of conflict.

7 Conclusions and extensions

As time passes it is becoming increasingly clear that in some regions of the world resource scarcity is a major causal and/or aggravating factor of domestic or international conflict and political unrest. Given the current trends, it appears unlikely that renewable resource scarcities will be alleviated in the near to medium term. In fact it is likely that such scarcities will worsen. A better understanding of the interactions between societies and resource scarcities and their consequences are therefore vital.

Resource scarcities and thier consequences affect us all. While Third World countries clearly face the problem of resource scarcity head on, the increasing globalization of our economies means that more money and resources from developed countries are being invested in countries facing such scarcities. Consequently an understanding of the links between economics, resources scarcity and conflict are for country risk analyses which determine the desirability of foreign direct investment.

This paper represents a f i rst step in the rigorous study of the links between renewable resource scarcities and conflict, and the characteristics of such conflict. The model, while admittedly simple, provides some interesting insights. The main implications of our model for policy is that initiatives based on technical innovation alone, such as enhancement of resource growth, increases in harvesting efficiencies, and increases in carrying capacity are likely to bring harm by making the system vulnerable to conflict and decreasing its stability. The resulting instability is likely to make conflict more likely. The model offer the key insight that population will respond positively to such innovations, increasing system volatility and lowering the equilibrium level of per capita resources. The other major policy implication
which arises from our analysis is the birth control is imperative. This policy helps to stabilize the system and moves its equilibrium away from the conflict zone.

The model can be developed in many directions which will further help in studying the links between population and resource dynamics, and conflict. Modeling directly competition between two population groups over a single renewable resource is one example. On the policy front, insight may be gained from modeling directly the possibility of storage of the resource to protect against the impact of negative shocks. Departing from a linear specification of fertility is another interesting extension. While these modifications are likely to aid in examining new policy insights they are unlikely to alter the policy implications discussed in the previous paragraph.
References


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