7. Explaining and predicting future environmental scarcities and conflicts*

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THE PROBLEM IN PERSPECTIVE

It is well established that unregulated property structures create incentives to overuse natural resources (Hardin 1968). The overuse of natural resources, in turn, creates scarcities, leading individuals and households to try to appropriate more resources for themselves by, for example, producing more children (Nerlove 1991; Dasgupta 1995). The result is an increase in population that further aggravates scarcities. The absence of regulations and predetermined dispute resolution schemes, along with growing scarcity, leads to incentives to appropriate resources by force. Armed conflicts ensue among rival bands whose leaders try to take advantage of the situation. This has been called the "tragedy of coercion" (Konrad and Skaperdas 1999).

A synthesis of interactions resulting from the absence of regulation, the exacerbation of scarcity, and the ensuing conflict constitutes a "triple tragedy of the commons" which describes the failure to achieve collectively optimal levels of population, resource use, and political power. We present our preliminary views on the causal mechanisms of this tragedy within a formal theoretical framework and then illustrate them through some empirical analyses and dynamic simulations.

* The editors would like to dedicate this chapter to the memory of Ellen Wiegandt, well-published analyst of Alpine ecosystems and sustainable development. "O gentle child, beautiful as thou wert, Why didst thou leave the trodden paths of men too soon?" (Percy Bysshe Shelley, *Adonais, An Elegy on the Death of John Keats*).

BASIC QUESTION

We take as the starting point Garrett Hardin's (1968) contention that weak or absent regulatory frameworks are the source of environmental scarcities. In other words, what matters is not the degradation of the environment per se but the incentive structures that in the long run lead to an inferior social outcome. It is the incentive structures that are at the origin of the overuse of environmental resources. Hardin thought that the absence of a private property system is specifically at the root of environmental deterioration. However, a subsequent empirical literature demonstrates that a balance between people and resources had been achieved in many parts of the world without recourse to private property structures (McCay and Acheson 1987). Moreover, Hardin had presented a "commonsense" argument, limited to the very narrow context of cattle herding on a meadow whose access is open to everyone. This open access feature leads then to overgrazing. A formalized version of Hardin's reasoning and a generalization of his approach was presented later by Dasgupta and Heal (1979). Their work shows that Hardin's presentation is a special case of a situation where individual incentives lead to socially inferior outcomes. They also insist that many of these incentive structures do not permit the development of long-term retaliation strategies to help foster cooperation.

To understand the problem raised by Hardin, one must look at the general question of how regulatory structures (such as property rights) can be initiated. As suggested by Dasgupta and Heal's analysis, some regulatory structures might not bring about optimal results. Some might be too restrictive to permit innovation and development; others might be too loose and imprecise to protect natural resources. In both cases, and especially in the latter one, conflicts are likely to develop. To show the existence of the linkage between "the tragedy of the commons," regulatory schemes, and conflict, we begin with the formal analysis developed by Dasgupta and Heal, applying it, with some significant modifications, to our central question.

The Dasgupta and Heal theory assumes the availability or production of two goods, one private and one collective, within a socio-economic system. Private goods exclusively affect the utilities (or preferences) of an individual purchaser up to the amount that he consumes. Collective goods, however, influence the utility of that same individual not only up to the quantity he consumes but also up to the amount consumed by all other individuals of the group. The formalization of these notions can now be presented.

FORMAL ASPECTS: COLLECTIVE GOODS

Assume N individuals (or households) in a particular social group g. Let x_i represent the quantity of the private good consumed by individual i and $g_1, g_2, g_3, \ldots, g_i, \ldots, g_N$, the amounts of the collective good used by individuals $1, \ldots, i, \ldots\ldots, N$. Thus one has:

$$u_i = u_i(x_i, g_1, \ldots, g_i, \ldots, g_N) \tag{7.1}$$

An important special case of 7.1 is:

$$u_i = u_i\,(x_i, \sum_{j=1}^{N} g_i) \tag{7.2}$$

That is, individual (or household) i's utility depends on the total quantity of the collective good consumed, purchased or produced by everyone. A crucial assumption resides now in the definition and specification of u_i.

Many models of rational behavior assume that utility functions are either risk neutral or risk averse. This is often done for mathematical convenience, to simplify complex issues. Experimental psychologists and even observers of animal behavior, however, have noticed that risk acceptance often characterizes choices when a decision-maker is faced with the prospect of losses (Stephens 1990). Risk aversion and risk-preferring behavior are regularly seen together within the same individual, and various attempts have been made to explain their joint appearance. The principal analyses of hybrid risk attitudes are Battalio et al. (1990), Battalio et al. (1985), Camerer (1989), Fishburn and Kochenberger (1979), and especially Kahneman and Tversky (1979). In particular, Fishburn and Kochenberger (1979) show that the majority of individuals have an everywhere increasing utility function $u(x)$, where x is a measure of gains and losses that increases more than proportionally for small or negative x and then less than proportionally for relatively high values of x. Many individuals are thus risk averse over gains and risk preferring over losses. This notion can serve as a theoretical justification for the contention elaborated by Hirshleifer (1991) that the poor have a comparative advantage in appropriation, obviously a more risky way to acquire wealth than capital accumulation through savings. In general, this type of utility function leads to very different but also quite plausible bargaining behavior as compared to traditional models.

A natural extension of these considerations is to represent an average decision-maker's utility function by an everywhere increasing S curve in x which adequately expresses the mix of risk aversion under gains and risk preference over losses.[1] An S-curved utility function does not just obtain as a result of psychological analysis. It may also result from productive

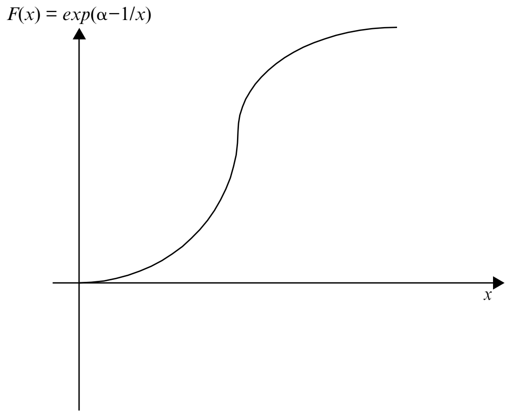


Figure 7.1 S-shaped utility curve

processes which exhibit first increasing and then decreasing returns to scale. If an individual agent is a producer and derives utility from the way they produce then they will also have an S-shaped utility function. This case will be discussed later.

Without loss of generality we can then present the following risk averse/risk preferring (S-shaped) utility curve as shown in Figure 7.1.

The utility function u_i is defined here as a marginally increasing then decreasing function of both the x_i and $åg_i$ of equation (7.2). It makes sense that, since the arguments x_i and $åg_i$ will be expressed in terms of values ranging from 0 to infinity, this kind of utility function starts at 0. Let us further assume that either all individuals are identical or very similar in their preferences or that agent i represents a median decision maker that sets the tone for what is happening in society. Consistent with this hypothesis, u_i can be rewritten as:

$$u_i\,(x_i, \sum_{j=1}^{N} g_i) = exp(\alpha - 1/x_i + -1/\sum_{j=1}^{N} g_i) \qquad (7.3)$$

The function $exp(\alpha\ -1/f(x))$ has precisely the S curve characteristic associated with prospect theory (Figure 7.1). One should also notice that both private and collective goods are essential for the utility of agent i, as it should be. If the value of one of the goods goes to zero, the value of the whole utility function goes to zero.[2]

Now assume that initially individuals have one unit of the private good x_i, and none of the collective good g_i. Agents are however able to convert the private good into the collective good at a rate p^s. If $s = 1$, the private good can be transformed into the collective good proportionally, if $s < 1$, the conversion takes place more than proportionally, if $s > 1$, less than proportionally. If, for instance, g_i stands for national defense, then s represents a measure of society's ability to mobilize resources for war (the lower is s, the greater the possibility to mobilize resources).

Agent i in society g can therefore maximize u_i as defined in (7.3) subject to a budget constraint:

$$p^s g_i + x_i \leq 1 \tag{7.4}$$

Several types of equilibria can be considered here. If all agents in society maximize utility in the same way i does, based upon some expectation they have on how much of the collective good every other agent produces or purchases, a particular kind of Nash equilibrium obtains for the society in question, which we will call a society market or anarchic equilibrium. Such an anarchic equilibrium constitutes a particular mix of a pure competitive equilibrium for private goods and a non-competitive but decentralized one for collective goods. Such a society market or anarchic equilibrium will obtain, as mentioned previously if every agent anticipates the purchase or production of the amount of collective good $\hat{g}$ by every other agent. For agent i, the problem is then to maximize:

$$exp\{-1/x_i + -1/[g_i + (N-1)\,\hat{g}]\} \tag{7.5}$$

by choosing x_i and g_i subject to the budget constraint (7.4). The necessary (and eventually sufficient since the utility function will after being initially convex become concave) conditions for an optimum will be:

$$Max\{exp\{-1/x_i + -1/[g_i + (N-1)\hat{g}]\} + l_i(1 - p^s g_i - x_i)\} \tag{7.6}$$

At the anarchic equilibrium, one can assume that $g_i = \hat{g}$ and thus $x_i = \hat{x}$. From the first-order conditions, we therefore have:

$$N\hat{g} = \frac{\hat{x}}{\sqrt{p^s}}$$

using again the budget constraint (7.4), gives for respectively $\hat{g}$ and $\hat{x}$:

$$\hat{x} = \frac{N}{\sqrt{p^s}+N} \text{ and } \hat{g} = \frac{1}{(\sqrt{p^s}+N)\sqrt{p^s}} \tag{7.7}$$

which is what every agent in the society under consideration is ready to produce or purchase as his bundle of private and collective good. One can notice here that if N is large and p^s relatively close to or equal to 1, every agent keeps most of their endowment in private goods and only a very small fraction is devoted to the collective good. However, our formulation of the utility function as S shaped has the advantage of establishing a relationship between the conversion rate p^s and the purchase or production of both private and collective goods. Thus, if p^s is relatively small, the voluntary provision of a collective good can become relatively high even with large N. Moreover, the expressions above show that, under some kind of "increasing returns" in the acquisition of the common good – that is, when the conversion rate p^s is relatively low (at least smaller than one) – the purchase or production of the collective good is relatively cheap and thus allows for a relatively large g per agent even if they consume or produce high amounts of the private good x. This illustrates the possibility that under circumstances of very low conversion rates, the production of both private and collective goods might be relatively high, which has then of course an incidence on the situation of a given society with respect to others.

Is such an anarchic equilibrium Pareto efficient? To answer the question one has to treat g as if it were another kind of private good and considered by agent i as if he was alone and thus maximizes:

$$exp\{-1/x + -1/Ng\} \text{ subject to the same budget constraint } p^s g + x \leq 1.$$

The Pareto optimal solution $(\tilde{x}, \tilde{g})$ can be found readily as:

$$\tilde{x} = \frac{\sqrt{N}}{\sqrt{p^s} + \sqrt{N}}, \; \tilde{g} = \frac{1}{(\sqrt{p^s} + \sqrt{N})\sqrt{p^s}} \text{ and thus, } \tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}} \tag{7.8}$$

Quite clearly, the anarchic equilibrium is not Pareto optimal. It reflects here the "tragedy of the commons" outcome where the absence or minimal provision of the collective good (here regulation) leads to a socially undesirable outcome. In fact, the difference between the anarchic equilibrium and the Pareto optimal value is:

$$\sqrt{p^s}\frac{1 + \sqrt{N}(\sqrt{N} - 2)}{N} > 0 \text{ for all } N > 1, \tag{7.9}$$

provided only positive values for the terms under the square root signs are considered. Expression (7.9) tells us that the anarchic equilibrium is identical with the Pareto optimal outcome whenever $N = 1$ as one would expect since it corresponds to the case where there is just one member of society, or in terms of property rights one owner who has then the incentive to provide for himself in an optimal way.

Is the anarchic solution thus always suboptimal? Not necessarily. If an efficient market can be established that includes all externalities, a Pareto optimal (a so-called Lindahl) equilibrium will obtain (Dasgupta and Heal 1979: 44–52). However, the creation of such a market implies the creation of an organization, a collective good, to define, then protect and guarantee Pareto optimality (for example in the form of property rights) for that market (Luterbacher 1994). The organization of such a market involves potentially considerable costs. If one wants to create a market for the collective good, another collective good is necessary to organize it, and so on. The situation leads to an infinite regress. It is difficult to imagine the creation of an efficient market for defense for instance. In most cases such a market will turn into a racket for protection because property rights will be neither well defined nor protected, since the use of force will make the temptation to extract rents from people one is supposed to defend, hard to resist.[3]

Given the necessity of at least an initial organization for the provision of a collective good, alternatives to externality markets have to exist in order to allow societies to move toward Pareto optimality.[4] This is the case with tax equilibria where societies agree or are forced to maintain collective goods with regular mandatory contributions.[5]

Unlike markets that do not presuppose any form of organization to solve collective good problems, the authority to tax assumes the existence of a social order that is ready to collect and enforce the collection of mandatory contributions in various forms by the members of society. However, as in the case of markets for externalities, the power to tax is far from obvious and requires the possibility to punish recalcitrant members. The imposition of taxes on a society is difficult without the consent of at least some of its members; and usually requires the existence of a relatively important level of transactions in some form of "numeraire" that can then be taxed. Political entrepreneurs can only overcome the first difficulty if they want to avoid seeking consent, when they can rely on their own private sources of revenue.[6] However, even in this case, the collective good could at least initially be supplied at a suboptimal level. The second difficulty, which can be illustrated by a significant reduction in the number of taxable transactions, is almost impossible to overcome without a reorganization of the social order.[7] Usually the organization of defense as one of the initial collective goods has the advantage of solving both the protection problem and the taxation problem since it gives to an authority both the means to use force toward the outside and the power to enforce tax collection. Is taxation thus a way to compensate for the absence of Pareto optimality in an anarchic equilibrium? The answer is quite clearly yes as long as the taxation is "Pigouvian,"[8] that is, if it is explicitly meant to correct for the Pareto inferior outcome represented by the anarchic equilibrium. We will thus also consider here a subsidy t that a social authority will give on the purchase or production of a unit of collective good by agent i and τ a tax (lump sum) that the authority imposes on i in terms of his private goods.[9] Agent i in the absence of any market for externalities maximizes:

$$u_i\,(x_i, \sum_{j=1}^{N} g_i) = exp(-1/x_i + -1/(\sum_{j\neq 1}^{N} g_j + g_i)$$

subject to:

$$(p^s - t)g_i + x_i \leq 1 - \tau \tag{7.10}$$

and where of course agent i chooses only x_i and g_i. By analogy with previous results, we get at equilibrium, assuming that $\bar{p}^s = p^s - t$:

$$N\bar{g} = \frac{\bar{x}}{\sqrt{\bar{p}^s}} \tag{7.11}$$

To get to the Pareto optimal result (7.8) with $\tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}}$, the net price $\bar{p}^s$ that an agent must pay for the externality should be $\bar{p}^s = \frac{p^s}{N} = \frac{Np^s}{N^2}$. Indeed, introducing this expression into (7.10) leads to the Pareto optimal value (7.8) restated above. Thus the authority must set the per unit subsidy of the collective good at $t = \frac{(N-1)p^s}{N}$. The authority must also set a lump sum tax on each agent again with the purpose of reaching Pareto optimality as defined by the values of $\tilde{x}$ and $\tilde{g}$ in (7.8). This lump sum tax τ, is thus:

$$\tau = \frac{\sqrt{p^s}(N-1))}{N(\sqrt{p^s} + \sqrt{N})} \tag{7.12}$$

One is now able to compute total authority expenditures and revenues on this basis. Total expenditures or subsidies for the collective good are:

$$N\tilde{g}t = \frac{N}{(\sqrt{p^s} + \sqrt{N})\sqrt{p^s}}\,\frac{(N-1)p^s}{N} = \frac{(N-1)\sqrt{p^s}}{(\sqrt{p^s} + \sqrt{N})} \tag{7.13}$$

Total revenues are:

$$N\tau = \frac{N(N-1)\sqrt{p^s}}{N(\sqrt{p^s} + \sqrt{N})} = \frac{(N-1)\sqrt{p^s}}{(\sqrt{p^s} + \sqrt{N})} \tag{7.14}$$

which is of course the same as (7.13).

In other words, under Pigouvian taxation principles, total expenditures equal total revenues and the collective good budget is balanced and leads to Pareto optimality, which establishes the taxation equilibrium. Expression (7.14) allows computation of the optimal size in terms of N of a coalition necessary to establish a Pareto optimal tax equilibrium. This size is given by:

$$\frac{\partial N\tau}{\partial N} = \partial\frac{\dfrac{(N-1)\sqrt{p^s}}{(\sqrt{p^s}+\sqrt{N})}}{\partial N} = 0$$

Which solution (for a maximum) eventually leads to:

$$N = -2\sqrt{p^s}(-\sqrt{p^s}+\sqrt{p^s-1})-1 \text{ or} -2\sqrt{p^s}(-\sqrt{p^s}-\sqrt{p^s-1})-1$$

where the second solution leads to higher values. One gets then N as a function of p^s increasing either exponentially if $s > 1$ and logarithmically if $s < 1$. This reflects the notion that if the transformation rate from a private to a collective good can be done cheaply (in some sense with increasing returns to scale), then the required coalition to establish it is much less important than when it can only be done at great expense (with decreasing returns).

Clearly, this analysis establishes the importance of numbers of people in the creation of collective-good-providing coalitions. More are necessary if the collective good is relatively expensive, fewer are needed if the collective good is cheap. However, there might be differential prices and thus costs within a society: one group might have cheaper access to collective goods than another which can lead to its domination. Moreover, if two or several groups have cheaper access to collective goods such as defense, armed conflict between them for the control of other resources might erupt. If such collective goods are still relatively expensive, then numbers matter and competitive recruitment efforts by each group will occur. Demographic processes may play a major role in providing subpopulations from which recruitment efforts can be undertaken. We now examine their evolution, their links to resources, their depletion, and their impact.

DEMOGRAPHIC PROCESSES AND RESOURCE DEPLETION

A population problem may occur on a particular delimited area when rates of population growth are overly high. For example, the growth rate of the sub-Saharan African region is between 2 and 3 percent per year, which should lead to a doubling of population in approximately 30 years. This can be thought of as an increased pressure upon the environment's carrying capacity since land and resources cannot be expanded at will. Demographers and economists have shown that bargaining theory can be applied to reproductive decisions inside the household (Lestaeghe 1986; Simon 1986). Indeed, the costs of bearing and rearing children are not equally shared by men and women: pregnancy entails forgone work-capacity and an increased probability of dying. Besides, caring for children is time-consuming and imposes material restraints on the disposal of income. Furthermore, in regions such as sub-Saharan Africa, one can expect "reproductive free-riding" on the part of men since the costs of rearing children can be spread (or shared) among kith and kin (Dasgupta 1998).

Dasgupta (1993, 1998) provides two answers to the possible divergence between decisions at the level of the household that seem rational and their effect on society as a whole. The first is that households get the wrong incentives because of inefficiencies in the relative pricing of various goods and services. The second is that each household imposes negative externalities onto others. One source of externalities has been put forward in the previous comment on open access resources: because of lack of restrictions to entry, open access to the resource provides an incentive to produce too many children since parents do not have to bear the full costs of rearing them. Another basis for externalities is simply the social environment: individual behavior can be dictated by norms and culture. Societies may have acquired customs and mores that favor high fertility rates. Such norms stem traditionally from historic conditions involving high mortality rates, low population densities, and high probabilities of war. However, they tend to survive as part of a community's identity even when the rationale for their existence has disappeared. In such circumstances, each household's utility is a function of its own actions and of the average actions of all others; that is, as long as all households seem to respect the norm, no one has an incentive to move away from it. For example, sub-Saharan African fertility regimes seem to a large extent affected by customs like low age at marriage, polygyny, weak conjugal bonds, and strong kinship support systems for children of the community (Lestaeghe 1986). Moreover, such social arrangements favor males, who get a disproportionate incentive to engender children since they only partially incur the costs of rearing them. The basic conclusion is that society as a whole can be stuck at a suboptimal Nash equilibrium with households producing too many children (and knowing it) because no one has a unilateral incentive to depart from this accepted pattern of behavior. As underlined by Dasgupta (1993), this is a typical coordination problem involving a multiplicity of Nash equilibria which can only be addressed through the regulatory activity of the state.

One puzzling feature of the sub-Saharan African demographic regime is that fertility rates have only begun to react to declining mortality rates.

This can be explained by Dasgupta's first hypothesis: children must be seen as goods providing various benefits to the household. Obviously, the first motivation for having children may be that they are an end in themselves. However, from the viewpoint of their parents, children may be considered as productive assets: given the constraints on saving in rural areas, children represent insurance for their parents in old age. More importantly, children in rural areas are an income-yielding asset. When agricultural output is low, energy and water prohibitively expensive (because of lack of basic infrastructure), and the possibility of investing in capital non-existent, people need to engage themselves in complementary activities such as collecting wood, monitoring cattle grazing, or fetching water. Children are therefore essential as workers for the survival of their family. Clearly, a positive feedback sets in: to the extent that property rights are ill-defined, high fertility rates imply further stresses on the environmental-resource base, which in turn give incentives for expanding the family, which will increase the depletion of the resource. Hence, resource scarcity and development are intrinsically related: investments in infrastructure in order to reduce for example the price associated to basic commodities such as fuel or water would decrease the value of children as income-earning assets. Similarly, increased savings and investment opportunities would lessen the need for children as a sort of insurance. Nevertheless, development programs thought to assure growth and modernization can also exacerbate resource degradation in the absence of clearly defined property rights.

Indeed, as stressed in Dasgupta and Heal (1979), no dominating strategy is available to actors operating in an open-access type of situation. Thus, the Prisoner's Dilemma is not an apt metaphor for such circumstances. However, one can clearly see that whereas no producer has a dominant strategy to keep on extracting more, no one can oppose a credible threat to prevent others from doing it. Hence, the behavior of actors in an open-access type situation is closer to that of players in a Chicken Game. The corollary of the absence of credible threats is the existence of an intense competition for the first move: the first mover enjoys a durable advantage over his opponent; this in turn yields a subgame perfect Nash equilibrium where gains (or losses) are disproportionately distributed in favor of the first. Given the asymmetry at the equilibrium, it is extremely difficult to reach another outcome, thus patterns of behavior exhibiting strong inequalities can easily be maintained over long time periods. Moreover, entitlements to the products in managed common-property systems across the globe have mostly been based on private holdings: such institutional arrangements tend therefore to replicate the inequalities in terms of wealth among participants at the level of resource use. Hence, even when access to a common pool resource is restricted, it is likely to provide the privileged with greater parts of the benefits. To be sure, the asymmetry in resources and capabilities provides the latter with credible threats when it comes to devise collective agreements to control the exploitation of the environmental base. Besides, one need not assume asymmetric players (for example elite versus non-elite) to obtain a stable unequal distribution of benefits accruing from the exploitation of the resource: such agreements are easily supported by specific types of retaliatory strategies (Dasgupta et al. 2005). Moreover, as scarcities occur (the availability of arable land diminishes) the bargaining power of certain population groups is altered by changes in relative prices: actors with few resources may put a premium on the short term. Indeed, in such instances, small parcels of land may be sold to powerful landowners to obtain liquidities rapidly. Furthermore, as competition intensifies, it becomes perfectly rational for individuals to overexploit the commons in order not to be the last one without resources to tap (Dasgupta and Heal 1979). Thus, resource scarcities may lead on the one hand to overuse by their users, and on the other to competition for appropriation between peasants and between peasants and landowners. Finally, the impact of the environmental resource base's depletion over customary rules and norms needs to be considered as well: as land becomes a commodity through market operations, it ceases to be ruled by customary norms and restraints (André and Platteau 1998). Actors are therefore more inclined to overexploitation and short-term calculations. This mechanism both illustrates and gives an answer to the paradox raised by examining the work of different authors concerning the relationships between environment and conflict: scarcities and abundance of resources are in the short term part and parcel of the same dynamic. Overabundance exists because incentives are present for more resource appropriation even when the price of the resources plummets because the opportunity cost of labor is cheap compared to what can be gained by selling it. However, it is precisely this overexploitation that leads eventually to scarcities.

Can one find these processes within the theoretical framework that was presented above? The answer, as we will now see, is clearly positive.

FORMAL ASPECTS: POPULATION

If overuse of resources at first leads to population increase, then incentives must be present within the formal structure that produce that outcome. To show that this is the case we will analyze two expressions that are derived from our formulation: (1)The individual utility of the representative agent within an anarchic equilibrium must increase with the growth in N, the population. (2) The gap between the anarchic equilibrium and the Pareto optimal situation where resources are not overused should increase as N rises. Both these conditions are fulfilled. The partial derivative of the utility function u_i (under anarchy or open access) with respect to N:

$$\partial u_i/\partial N = \partial\, exp\{-1/x_i + -1/[g_i + (N-1)\,\hat{g}]\}/\partial N = 1/N^2(p^s + \sqrt{(p^s)}$$

is always positive.

The gap between the anarchic (open access) equilibrium and the Pareto optimal situation is:

$$\sqrt{p^s}\frac{1 + \sqrt{N}(\sqrt{N} - 2)}{N}.$$

Its partial derivative with respect to N is: $(N - \sqrt{N})\sqrt{p^s}\frac{1}{N^{\frac{5}{2}}}$

which is always positive for $N > 1$.

We thus can reproduce the paradox described earlier: there is an individual incentive to increase N even though a greater N deteriorates the overall social situation. What are the consequences of these processes for conflict?

There exists a well-developed literature about the "resource curse," the negative impact of natural resources on economic growth. This literature is largely empirical, and only a few of the contributing scholars do not only test for the negative impact of natural resources on growth, but also inquire how natural resources can influence growth. Most of the papers which treat particular relations focus on economic aspects such as the Dutch disease, which refers to the impact of natural resources on relative prices and on the terms of trade. Some articles, however, have found empirically that one reason why natural resources tend to decrease growth is the risk of conflict, political instability, and poor institutional quality (see Baland and Francois 2000; Gylfason 2001; Ross 2001; Sala-i-Martin and Subramanian 2003; Bulte et al. 2003).

Only a handful of scholars have yet attempted to measure empirically the direct link between natural endowments and civil unrest. Most of these scholars have used a case-study approach and have found that natural resources have been an important reason for conflict within a particular country (see, e.g., Frynas and Wood 2001; Englebert and Ron 2004; Angrist and Kugler 2005). However, few cross-sectional country statistical studies have been performed so far. A notable exception is Ross (2004), who concludes that some natural resources such as oil increase the risk of civil war, whereas the existence of other kinds of natural resources such as gemstones and drugs increases above all the length of conflict.

Collier and Hoeffler (1998) conducted an econometric study about the likelihood of civil war and came to the conclusion that the effect of natural resources on the risk and duration of civil war is non-monotonic:

> The possession of natural resources initially increases the duration and the risk of civil war but then reduces it . . . In effect, possessing natural resources makes things worse, unless you have plenty of them. The effect is again quite strong. At the means of other variables, a country with the worst amount of natural resources has a probability of war of 0.56 as against one without natural resources of only 0.12.

A few theoretical papers have attempted to explain why an endowment in natural resources can result in conflict. An interesting contribution by Skaperdas (2001)[10] shows that a higher availability of rents from resource production leads to more competition among warlords, which ends eventually with more resources being wasted on unproductive arming and fighting. Furthermore, Skaperdas shows that rents from natural resources like oil, gas, timber, or diamonds, or even foreign aid, can crowd out "ordinary" productive activities in an economy. Reuveny and Maxwell (2001) and also Grossman and Mendoza (2003) show through a dynamic analysis that natural resources can lead to conflict.

Another important consequence of the abundance of natural resources has been described by Tilly (1992): political entrepreneurs (or in our case warlords) are less dependent on tax revenues, if they operate within an area rich in natural resources. Because they can completely rely on rents and do not need tax revenues, they are not forced to seek consent, which is required for an operating taxation system. As a result, the democratization process does not take place.

Even though all these papers provide interesting insights into the link between natural resources and conflict, several important problems remain unsolved. Our model attempts to address some of those challenges. First, all the mentioned papers take the stock of natural resources as exogenously given and ignore resource exploitation issues. To fill this gap we explicitly address the exploitation question with the help of production functions for natural resources showing crowding. Second, our model is characterized by multiple equilibria, where one of them corresponds to a so-called "fighting trap." We will point out the difficulties of getting out of such a trap. This illustrates also the linkages between resource scarcities and conflict.

FORMAL ASPECTS: FIGHTING

The objective of the model is to explain a representative agent's choice between producing and joining fighting forces in an unstable country. This perspective can help clarify the conditions under which the emergence of a society with competing warlords (as sometimes occurs in developing countries) is more or less likely than the building of a politically stable and economically developed society. Moreover, we link the question of warlord competition to the issue of natural resources. We start from the following assumptions:

- Assumption 1: We assume a primitive society with *N* identical individuals, who can be symbolized by one representative economic agent.
- Assumption 2: The representative economic agent has the choice of how much time they want to allocate to production and how much to fighting.[11] In our model this will be represented by a decision to optimize by using a certain proportion of their time to produce and thus to contribute to a stable political regime and by using the remaining time to establish a "warlord society" through fighting.
- Assumption 3: The individual choice of the representative agent is linked to the aggregate decision of the society. If our representative economic agent achieves a higher expected value by fighting, and vice versa, we can expect that this outcome will eventually hold for the society as a whole. We can draw an analogy here to Schelling's (1971, 1979) binary decisions in an aggregate framework: the decision by one individual is conditioned by what all others are doing. So for instance if everybody drives to work it makes sense from an individual point of view to take public transportation because the roads are crowded. However, if most people take public transportation it is again worth driving. As shown by Moulin (1982 [1986]), this condition can lead to stable or unstable Nash equilibria at the level of the whole society.
- Assumption 4: Every agent is a producer/fighter and at the same time a consumer. The framework is the one of an economy, in which initially no trade with the outside is taking place but then eventually the economy opens up to trade.
- Assumption 5: If the agent becomes a fighter, they can make an initial gain at the beginning of the period by exploiting some of the natural resources. By contrast, becoming a producer demands an initial commitment, an investment. This initial investment can be for example the cost of education, or in a more agricultural society the cost of creating tools and machines for further development of productive activity.
- Assumption 6: The only choice made in this society is one between fighting and productive activities. We thus ignore for the moment the

question of how warlords emerge or how they organize their armies. We assume that in an environment where lots of people are willing to fight or where our representative agent devotes most of their time to fighting the emergence of warlords capable of organizing armed bands is more likely. Our model presents necessary but not sufficient conditions for organized internal conflict.

We want to find the level of producing/fighting which maximizes the utility of a representative agent. The model is a static, one-period model, in which the representative agent is a utility-maximizer who chooses an individually optimal level of producing and fighting.[12]

The representative agent has the following aforementioned utility function:

$$u_{pf} = \int_{i=1}^{n} c_i^D, \tag{7.15}$$

where c_i^D is the demanded amount of a variety of the only consumption good.

For convenience, all goods produced under a regime of "warlord" or "stable political regime" production can be seen as varieties of one single good, where each of them gives an identical level of utility to the representative agent.[13]

As our locally non-satiated representative agent is at the same time the only producer and consumer in our competitive economy, and as all relative prices are positive, the aggregate demand for every variety of our commodity must equal its aggregate supply. Since we have only one agent, and by assumption initially no international trade takes place, we get:

$$c_i^D = c_i^S, \tag{7.16}$$

where c_i^S is the produced (and supplied) amount of commodity i.

As the utility function is strictly monotonic in all varieties of the consumption good, and the agent basically consumes what he produces, we can focus exclusively on the production function of the goods. In order to maximize his utility, our agent simply maximizes production.

Every variety c_i^S has an identical production function, akin to the utility function (7.3) presented earlier:

$$c_i^S = \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) \tag{7.17}$$

where a = parameter, p = portion of time allocated for producing, q = portion of time allocated for fighting, θ = parameter expressing the gain of producing, π = parameter expressing the gain of fighting.

This production function exhibits at first increasing then decreasing returns with respect to the arguments p and q. This expresses the plausible assumption that initial increases in the levels of respectively fighting or producing activities will generate more than proportional returns in the production good c_i^S but then eventually, with further increases of p and q, less than proportional output will appear. If everything that is produced is consumed agent i has simply the utility function $u_{ipf} = c_i^S$. This utility function is similar to the S-curve preference functions we introduced earlier. This production/utility function is subject to the constraint:

$$(1 - b)q + (1 + k)p \leq 1 - t + k \textit{ with } t >> b \tag{7.18}$$

By definition, $p + q \leq 1$ since both variables represent parts of a total endowment. However, the initial commitment (analogous to a tax) for becoming a producer, called k, and b, the initial gain (analogous to a subsidy) of turning a producer into a fighter, will also affect the endowment as a whole.[14] The "subsidy" to the fighter usually has to be more than compensated through a tax on the total endowment, t, which is assumed to be considerably greater than b. Similarly, the commitment taken by a producer, k, which is a net contribution to the total endowment, has to be accounted for. All these considerations are represented in the constraint (7.18).[15]

Thus, we assume that there are two ways of producing a particular good. Either the agent can choose the "stable political regime" production technique under which they have to make an initial commitment in order to get a higher return in the long run or they can choose the "warlord" production technique, which refers to the low-technology capability of exploiting natural resources in areas controlled by the armed forces and gets an initial boost from the switch to fighting.

The terms θ and π correspond to the elasticity of producing and fighting, or to put it differently, to the impact of a marginal change in the amount of production and fighting time on the output.

The link between the outputs of the two rival production techniques is summarized in equation (7.19). The decision-taker is myopic and only takes the short and medium run into account. As he ignores the future externalities of overexploitation, he has incentives to extract more than the social optimum of natural resources:

$$\theta = \pi(1 - \phi) + y \tag{7.19}$$

where $\phi = xE - z$; where y = ordinary production in case of producing, z = short-run gain of overexploitation, E = externality of the overuse of the natural resources (positive number), x = extent up to which the externality can be internalized if the agent is a producer (number between 0 and 1).

It is a priori difficult to determine whether $\theta > \pi$ or $\pi > \theta$, as the latter, π, benefits in the short run from the gains of the overexploitation of natural resources (z) and as the former θ implies regular production and efficiency gains from the better internalization of the externality. The short-run gains from overuse correspond to the increased quantity of natural resource exploitation, whereas the gains of better internalization of the natural resources correspond to a higher sale price (as less is produced) and to a more efficient exploitation of natural resources. The influence of y, ordinary production, is ambiguous: if we have $y < \theta$, then we are in a "normal" situation. We will first assume that the overuse of natural resources is quite an important factor and that accordingly θ is smaller than π.

The values of x and y depend on the following factors (by assumption property rights protection and the possibility of joining an international cartel become only real options in the case of the "stable political system" production technique).

$$x = x(\overset{+}{p_M}, \overset{+}{p_P}) \text{ and} \tag{7.20}$$

$$y = y(\overset{+}{p_P}) \text{ and} \tag{7.21}$$

$$p_M = p_M(\overset{+}{p_P}) \tag{7.22}$$

where p_M = probability that an international cartel of producers of the natural resource takes place (number between 0 and 1), p_P = probability that the rule of law and property rights are protected (number between 0 and 1).

We can see in equation (7.20) that if the representative agent chooses to be a producer rather than a fighter, a gain due to the internalization of the externality, xE, is possible, if an international cartel of the producers of the particular natural resource takes place or if the property rights are better protected than in the warlords case. An international cartel fights the price-depressing effect and restricts the quantity (less overuse) to keep prices high.[16] A good level of property rights protection assures a more efficient exploitation of natural resources. In addition, as described by equation (7.21), a high level of property rights protection may also favor the "regular" production y.

Equation (7.22) stresses furthermore that a society with a certain control of the quantity produced (due to the protected property rights) is more likely to form an international cartel with other similar societies.

Using (7.17) and (7.18), we get the following production maximization problem:

$$\underset{p,q}{Max} \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) \text{ subject to } (1 - b)q + (1+k)p \leq 1 - t + k, \quad (7.23)$$

and from (7.19) after transformation $\pi = \frac{\theta - y}{1 - \varphi}$.

This can be expressed by the following Lagrangian:

$$L = \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) + \lambda(1+k-t-(1-b)q-(1+k)p) + \mu\left(\pi - \frac{\theta - y}{1-\varphi}\right) \quad (7.24)$$

Calculating the partial derivatives of L with respect to$p$, q, λ, μ (the first-order conditions) gives us equation (7.25) after rearrangement:

$$\frac{\pi}{q^2} = \frac{\theta}{\frac{(1 + k - t - (1 - b)q)^2}{(1 + k)^2}} \quad (7.25)$$

After rearranging (7.25), we can distinguish two possible equilibria (all other possibilities violate the restriction $0 \leq q \leq 1$) which we obtain by taking the square root on both sides. We get:

$$q_1 = \frac{1 - t + k}{1 - b + \sqrt{\frac{\theta}{\pi}}(1 + k)} \text{ and} \quad (7.26)$$

$$q_2 = \frac{1 - t + k}{1 - b - \sqrt{\frac{\theta}{\pi}}(1 + k)} \quad (7.27)$$

As expected, a higher b and a higher k result in a higher chosen level of fighting activity, since the first partial derivatives of (7.26) and (7.27) with respect to b are:

$$\frac{\partial q_1}{\partial b} = \frac{1 + k - t}{\left(1 - b + (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \text{ and} \quad (7.28)$$

$$\frac{\partial q_2}{\partial b} = \frac{1 + k - t}{\left(1 - b - (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \quad (7.29)$$

These are always positive, provided $t < 1+k$. In addition, it can also be shown that the first partial derivatives of q_1 and q_2 with respect to k are positive. They are:

$$\frac{\partial q_1}{\partial k} = \frac{1 - b + t\sqrt{\frac{\theta}{\pi}}}{\left(1 - b + (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \text{ and} \tag{7.30}$$

$$\frac{\partial q_2}{\partial k} = \frac{1 - b - t\sqrt{\frac{\theta}{\pi}}}{\left(1 - b - (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \tag{7.31}$$

The equations (7.30) and (7.31) are always positive if $1 \geq b + t\sqrt{\frac{\theta}{\pi}}$.

Interesting consequences appear, when θ and π, the elasticities of producing and fighting, or to put it differently, the impact of a marginal change of the amount of production and fighting activity on the output, are considered.

In the case of the "good" equilibrium q_1 (where q is low), an increase in θ decreases q (the partial derivative of q with respect to θ is always negative). This seems intuitive for a situation in which incentives work properly. By contrast, for the "bad" equilibrium q_2, the so-called "fighting warlords trap," a greater value of θ actually increases q (the partial derivative of q with respect to θ is always positive). The equilibrium value q_2 is a "high" conflict outcome, where a great proportion of the population has an incentive to engage in fighting rather than producing through more conventional means. This means that when fighting is generalized in our model, even an increase in the elasticity of traditional production will not only leave the situation unchanged but will push an even higher proportion of the population into fighting. The society in question is then caught in what can be called a "fighting warlords trap."

However this process has a limit which is given by the ratio $\frac{\theta}{\pi}$. If θ is greater than π, then the denominator of the fraction which determines q_2 becomes negative and thus q_2 itself is negative, which contradicts our assumptions. Thus, if $\theta > \pi$ only the q_1 solution is possible. The ratio $\frac{\theta}{\pi}$ constitutes thus a bifurcation which establishes the possibility of such a "fighting warlords trap." Increasing θ substantially through better internalization of the natural resource externality or greater capacity to produce without fighting will make the "warlord trap" equilibrium impossible.

Thus, the higher the profits made with natural resources under a stable political system regime are relative to those made under a system of competing warlords, the less likely is the latter to occur. Also a higher value of the regular production (exclusive of natural resources) makes the emergence of a liberal democracy more likely.

Further, higher probabilities of an international cartel for the natural resource, *Pm*, and of an operating property rights protection and rule of law system, *Pp*, increase the likelihood of a liberal democracy outcome by increasing x and y in equation (7.19). On the other hand, higher immediate gains from fighting, b, and higher initial commitments for producing, k, increase the risk of civil war.

If the immediate gains from natural resources, b, have a clearly negative impact on democratization and the establishment of the rule of law, the impact of π depends on the values of several other parameters. To deal with those, recall that equation (7.19) expresses θ in terms of $\pi\theta = \pi(1 - \varphi) + y$.

This relation illustrates the idea that if the gains of the natural resource exploitation technology under a regime of warlordism, π, are bigger than the gains of production in a stable political system, θ, it is because of the bigger quantity of natural resources exploited, due to overuse.

Clearly, these bigger gains from the warlordism exploitation technology are not sustainable in the long-run because of the negative impact of over-exploitation. From an evolutionary point of view the gain from exploiting natural resources, π, should approach zero in the long run.

It is interesting to see what the implications of extreme values of π are on the level of q. If we replace θ by its value defined in relation (7.19) we get the following equations:

$$q_1 = \frac{1 - t + k}{1 - b + \sqrt{\frac{\pi(1 - z + xE) + y}{\pi}}(1 + k)} \tag{7.32}$$

$$q_2 = \frac{1 - t + k}{1 - b - \sqrt{\frac{\pi(1 - z + xE) + y}{\pi}}(1 + k)} \tag{7.33}$$

For a very small q, we get, in the square root found in the denominator of the above fractions, almost just the standard (as opposed to the resource) production, y, divided by a very small number, which results in the value of the square root becoming increasingly large. We have thus:

$$\lim_{\pi \to 0} q = 0 \tag{7.34}$$

By contrast, as π approaches infinity, y/π becomes very small within the square root, which leaves:

$$\lim_{\pi \to \infty} q = \frac{1 - t + k}{(1 - b) \pm \sqrt{(1 - z + xE)}\,(1 + k)} \qquad (7.35)$$

Thus, within the framework of the present model, a very low level of natural resources decreases the risk of a civil war outcome to close to zero, whereas for medium and high levels of natural resources we obtain higher levels of q. But the relationship between π and q is not monotonic. These implications are in accord with the empirical findings of Collier and Hoeffler (1998).

The resulting ambiguity could indicate that too huge an abundance of natural resources has a negative impact on political stability and development if the resources are easily accessible (high b). If taking full benefits from the natural endowments requires an important investment (low b), as is for example the case for oil, the risk of civil war is smaller. This could explain why most of the oil-producing countries have more or less stable regimes despite huge amounts of natural endowments.[17] However, the fact that we get multiple equilibria is an interesting feature of the present model. It indicates that it might be possible for a society to get stuck in a "fighting trap," escape from which requires specific policy measures and possibly international cooperation.

We can see that a pure "stable political system" equilibrium with a low level of fighting is only feasible if the additional gains from such a regime are more important than the commitment required in terms of the initial investment of producing, k, and the opportunity cost of the immediate gain of becoming a fighter or a bandit, b. In other words, a democratic society can only stay peaceful and stable if it offers a perspective for the future, a kind of "American Dream" to its members. This is the case in a meritocratic society in which higher education and job opportunities are available for anybody who is willing to work hard enough to succeed. Conversely, if the expected gains of being honest are smaller than the immediate gains of being a criminal (or fighter), people tend to become criminals.[18]

By and large, we can see that overexploitation of natural resources is, among other factors, due to the impact of the absence of an international cartel and to a lack of property rights protection. Both problems are enhanced by warlord competition within a society, which up to a certain point is more likely to occur in areas where big quantities (or highly valued amounts) of natural endowments are easily accessible. Essentially, we have to deal with a vicious circle of natural resources leading to fighting activity, which leads to an overuse of natural resources, where the profits made are used for further fighting and so on.

How do these findings link up with population dynamics? The crucial relationship is again the equation that relates the choice to produce or to fight to natural resource use and production:

$$\theta = \pi(1 - \varphi) + y$$

If φ, which expresses the degree to which the society is unregulated and property rights are left unprotected, is assimilated to the difference between the anarchic equilibrium and the Pareto optimal situation established in our initial model we have a way to analyze whether population growth under the anarchic equilibrium also increases the value of q, the optimal choice for fighting as opposed to producing. Such an analysis will show if our model which represents the choice between fighting or producing is capable of expressing the notion that an increase in population under anarchic conditions leads to a greater proportion of choices to join warlords instead of producing. As established before, the optimal choice leads to two values in terms of the proportion of activities devoted to fighting as opposed to producing: a high one, a "bad" equilibrium; and a low one, a "good" equilibrium outcome. We will concentrate our analysis on the high one and ask whether an increase in N leads to an increase in q_2. Quite clearly this is the case under the specific conditions that $N > 1$ which is obvious and the ordinary productive activity $y > \theta$. This condition implies furthermore that:

$$\varphi = \sqrt{p^s \frac{1 + \sqrt{N}(\sqrt{N} - 2)}{N}} > 1 \text{ for } \pi > 0.$$

What this means is that overproducing and overexploitation of natural resources has to take place in order for a demographic increase to eventually produce more fighting activities. In other words all population increases do not lead to these detrimental results. According to our model, only those that are linked to resource overuse and depletion are likely to generate civil wars and warlord societies.

DYNAMIC ASPECTS

The dynamics of open access or unregulated social systems can be conceived as the interaction between a resource stock and a population that uses it. If the resource stock is finite it will eventually be depleted. It is however possible to deplete it at an optimal rate which should allow timely

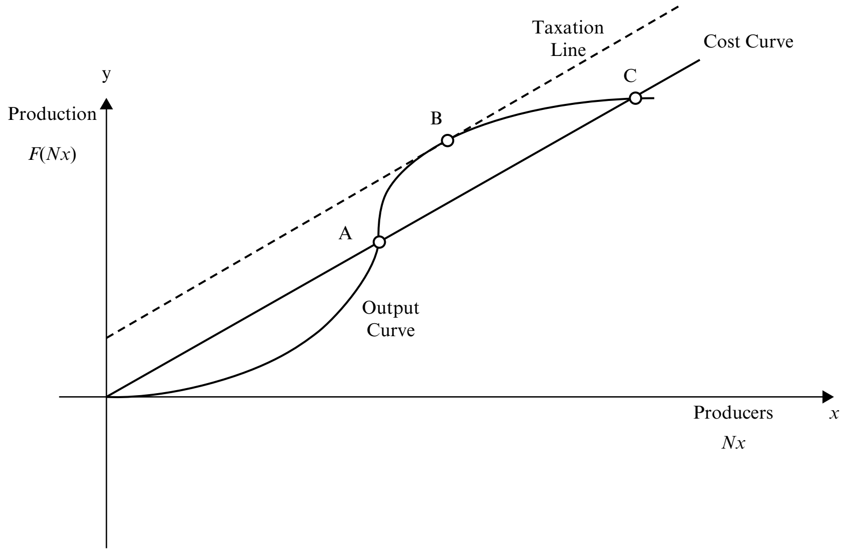


Figure 7.2 Production and costs as a function of number of producers

switches to the use of other resources. If the resource is renewable, the particular dynamics of its evolution will have to be taken into account, especially given the fact that the population will use it. Let us imagine that in a simple production system that relies on a renewable resource (such as fishing), the cumulative production can be represented by an S-shaped curve, while cumulative production costs can be expressed as a straight line if constant unit costs per individual producer are assumed. The production issue in an open access system can be illustrated by the graph in Figure 7.2.

Figure 7.2 shows that up to A, marginal productivity is higher than average productivity but that the output curve is lower than the cost curve. In other words there is an initial investment to be made in terms of sunk costs in order to reap the benefits of greater outputs, which are achieved after point A. The problem, in terms of a collective good creation, is to convince (or to force) enough producers to participate in view of the condition that average product (which motivates producers always in a collective good situation) is lower than marginal product.

After point A, the problem is opposite in the case of Figure 7.2.[19] Output outstrips costs and surpluses are generated which reach their maximum at point B where the slope of the output curve is equal to the marginal cost. If more and more population producers with their inputs are allowed into the process, the maximum at point B is passed, the whole surplus is dissipated at point C, and one is faced with the familiar tragedy of the commons. It can be noticed that if a Pigouvian tax is imposed on production proportional to costs then maximum profit can be reached at point B, which can then be interpreted as a tax equilibrium.

In the absence of taxation and regulation however we can formulate the above considerations in terms of two dynamic differential equations, which describe, firstly, the evolution of the resource stock with the basic assumption that it grows subject to its own natural dynamics minus what is being produced (that is, extracted from it):

$$\frac{dz}{dt} = H(z) - F(z, Nx) \tag{7.36}$$

where z is a variable that represents the resource stock and $F(z,Nx)$ a cumulative production function similar to the one in Figure 7.2 which takes into account the amount of productive input x provided by N users so that one has Nx.

Secondly, the evolution of the number of inputs x, which is proportional to profit, defined as revenue minus cost, a dynamic that reflects exactly the process leading to surplus dissipation in Figure 7.2:

$$\frac{dNx}{dt} = \mu q(F(z, Nx) - pNx) \qquad (7.37)$$[20]

where x again represents input per producer, $F(z, Nx)$, a production function, q the price of the product and p the cost of a unit of input and where μ is an adjustment constant between revenue and cost in terms of additional inputs x. In other words, equation (7.37) tells us that new entrants (represented here by more inputs) will move into this productive activity as long as profits can be made. This occurs of course because no limits are placed on engaging in that activity exactly as assumed also in Figure 7.2. Equations (7.36) and (7.37) are in fact general forms of the Lotka–Volterra equations which describe in mathematical terms evolutions of prey and predator populations. In general if one deals with a subsistence type economy, we can consider a relatively fixed input so that we can set $x = 1$ such that only the dynamics of N, the population matter. Clearly, left to themselves these dynamics will usually lead to resource exhaustion and hence population collapse. Such population collapses are also often preceded by conflicts, as for instance in the case of Easter Island.[21] We can assume, based upon the theoretical reasoning included in our previous model, that such conflicts erupt when individuals find it more attractive to appropriate by force rather than to produce. We can readily see how a combination of the dynamic formulations suggested above and the static models developed previously can account for the empirical evolutions of collapsing or severely conflict ridden societies (such as for instance Rwanda). An illustration of a conflict situation can easily be derived from the above relations. Assume that a resource stock is the object of a competition between two groups which we can designate as populations N and M. Their respective production functions based on the resource z can now be designated as $F(z, N,M)$ for population N and $G(z, M, N)$ for population M. We can assume that the productive activities of either N or M might interfere with each other (usually negatively) and thus the production functions should include the size of the other population as an input. Keeping our previous assumptions, we have:

$$\frac{dz}{dt} = H(z) - F(z,N,M) - G(z,M,N) \tag{7.38}$$

And respectively:

$$\frac{dN}{dt} = \mu q(F(z,N,M) - pN) \text{ and} \tag{7.39}$$

$$\frac{dM}{dt} = \nu k(G(z,M,N) - sM) \tag{7.40}$$

We assume that ν and k stand for the second population M for their speed of adjustment and their price respectively. From equation (7.38), we can now replace $G(z, M)$ and $F(z, N)$ by their values and introduce these into equations (7.39) and (7.40) which gives:

$$\frac{dN}{dt} = \mu q\left(H(z) - \frac{dz}{dt} - G(z,M,N) - pN\right) \tag{7.41}$$

and

$$\frac{dM}{dt} = \nu k\left(H(z) - \frac{dz}{dt} - F(z,N,M) - sM\right) \tag{7.42}$$

We can now make the following assumptions connected to conflict. Let us assume that the resource stock z is changed from a variable increasing (or decreasing) quantity to a fixed amount z^*. As a result we can reinterpret $H(z^*)$ as a fixed amount of z^* available for use. Since z^* is fixed, it makes sense to posit that:

$$\frac{dz}{dt} = 0$$

We are then left with the following differential equations:

$$\frac{dN}{dt} = -\mu q G(z^*,M,N) + \mu q[H(z^*) - pN] \text{ and} \tag{7.43}$$

$$\frac{dM}{dt} = -\nu k F(z^*,N,M) + \nu k[H(z^*) - sM] \tag{7.44}$$

If now $G(z^*, M, N)$ and $F(z^*, N, M)$ are Cobb–Douglas type production functions: $M^{\alpha}N^{\beta}$, then (7.43) and (7.44) become:

$$\frac{dN}{dt} = -\mu q M^{\alpha} N^{\beta} + \mu q[H(z^*) - pN] \text{ and} \tag{7.45}$$

$$\frac{dM}{dt} = -\nu k N^{\delta} M^{\gamma} + \nu k[H(z^*) - sM] \tag{7.46}$$

These are generalized forms of the dynamic Lanchester (1916) concentration or dispersion combat equations which describe the evolution of two population groups (or armed forces) opposed to each other in a violent confrontation. In particular, when $\beta = \gamma = 0$, $\alpha = \beta = 1$, we get a form of Lanchester's square law, where troop concentration leads to more than proportional casualties on enemy forces and when $\beta = \gamma = 1$, $\alpha = \beta = 1$, we get a form of Lanchester's linear law where dispersed forms of combat lead to proportional casualties on the other side. We can therefore establish how competition for a resource can lead directly to an armed conflict when the resource is finite. We should thus be able to apply some forms of the Lanchester combat equations to conflicts connected to resource scarcities.

EMPIRICAL ANALYSIS

These latter considerations lead to the question of the empirical evidence behind our formulations. While our ultimate goal is to simulate conflicts that might occur as a result of resource overuse in order to permit predictions of future confrontations, we will present at first some cross-sectional empirical data that support our ideas. A dynamic simulation of a resource-based conflict will then be carried out. For this we chose the case of Rwanda where between 500 000 and 800 000 people were killed in 1994.

The cross-sectional research should at least provide some evidence for the following. First, if property rights and regulatory frameworks work properly to protect resources, demographic incentives should work correctly and not lead to uncontrolled expansion. In particular, the desired level of children per household should be shown to adjust to the perspective of achieving a given degree of wealth in the future. Second, demographic variables and political regime characteristics should be linked. Third, linkages between some demographic and geographic variables and internal conflicts should be demonstrated.

There is some anecdotal evidence for the first type of linkage in particular in the demographic history of France. The introduction of well-defined property rights and a civil code as a result of the French revolution and Napoleon's reforms seem to have led the country into an era characterized by both the demographic transition and slow population growth even though France remained essentially an agricultural economy. More systematic analyses were carried out in the Swiss Alps by Ellen Wiegandt (1977; see Appendix 7.1 below) who showed, with the help of statistical investigations, that parental wealth was a strong predictor of the number of children. Relatively wealthy parents had more children than poorer ones. Clearly, if this is the case, incentives are present that internalize the costs of having children since family size will be commensurate with wealth or landed property and thus population will be prevented from expanding in an uncontrolled way.

The second linkage, between political and demographic regimes, also receives empirical support from the work of Rana Crevier (2005) who undertook linear multivariate regressions showing the relationship between type of regime (more or less autocratic) and demographic variables. The most significant results are reproduced in Appendix 7.2. They point quite clearly to the importance of one key demographic variable, the fertility rates, in explaining regime type. Crevier shows that the higher the fertility rate, the more autocratic the regime. Obviously other variables such as religion and the general status of women within the given society also play a role. In general, higher status for women is correlated with less autocratic regimes.

The third relationship between geography and demography has been examined more closely with the help of the Uppsala–PRIO (Peace Research Institute Oslo) internal conflict data set by Sébastien di Iorio (2005). Here, the density of population related to the surface of arable land seems to be the best predictor of internal conflict (results in Appendix 7.3).

Putting these empirically based relationships together, we can hypothesize that there may even be a temporal sequence implied by these linkages. In a first stage, strong demographic expansion would lead to political difficulties that in turn lead to autocratic regimes. In a second, these autocratic regimes would eventually collapse as the children produced by the demographic expansion reach adulthood and contribute to an excessive population density. The scarcities resulting from population pressure on resources could lead to civil strife, ultimately overturning the regime.

Rwanda represents a case where such a sequence might have been at work. We will now analyze it.

Rwanda has had a very difficult history of social and economic relations even before independence in 1962. Tutsi minority resistance to the government was at first unsuccessful because the government of President Juvenal Habyarimana was able to promote agriculture, the main economic activity of the country, through substantive extensions of the areas under cultivation at the expense of marshes and forests but also through the reoccupation of plots abandoned by segments of the fleeing Tutsi population. Eventually this policy reached its limits and was especially unsuccessful at checking population growth. Rwandan agriculture has always been prosperous thanks to favorable climatic and ecological conditions. As noted by Prunier (1995), "the whole country looks to some degree like a gigantic garden, meticulously tended, almost manicured resembling[22] more the Indonesian or Filipino paddy fields than the loose extensive agricultural pattern of many African landscapes." The agricultural development strategies implemented by the government bear a considerable responsibility for the scarcities that occurred from the mid-1980s onward. Indeed, caloric production per capita increased by 22 percent between 1965 and 1982, only to fall back to its 1960s level in the last decade of the century (André and Platteau 1998). To the extent that the per capita production of food crops followed the same pattern (ibid.), one must question the strategy set up by the Rwandese authorities. In particular, the relation linking the abundance of natural resources and the form of social and political controls it implied seems critical to understand the dramatic events that took place in 1994.

Two policies that were put into place stand out. First, the government's strategy mainly promoted developing new land and decreasing fallow land, resulting in increasing returns being based overwhelmingly on land extension (by clearing forests and draining marshes). The limits to such a strategy were reached as population densities eventually converged across the country, as compared to the wide disparities that prevailed until recent times (André and Platteau 1998). Moreover, the production technology remained highly traditional and faced severe problems of erosion and soil mining (due to the utilization of forested and pasture land for cultivation). The second aspect is the emphasis put on food self-sufficiency, illustrated by the fact that the country's per capita exports are among the lowest in the world (André and Platteau 1998), proscribing the abandonment of low-yielding, traditional crops.[23] Thus, in the face of a sustained population growth of well over 3 percent per year, it is not so surprising that famines reappeared by the late 1980s in several areas (André and Platteau 1998).

Land in Rwanda was mostly communally owned. Well-defined property rights were never established and the population was led to believe that the government and not individuals was the provider of land. In fact, in Rwanda, given official policies, the government was probably seen as the provider of land of last resort, especially if more could be appropriated from weaker minority groups. Given such expectations, demographic incentives worked in the wrong direction: the population was led to believe that the possibilities to cultivate land were limitless and thus more children were produced. In accordance with Demsetz's ideas, a land market eventually developed when population growth and density led to land scarcities. Such a market has seen a rapid increase in activities in the area studied by André and Platteau.[24] They report that although parcels of land cannot be sold under a critical threshold of 2 hectares, transactions increased substantially. This implied a wide set of consequences similar to what one would find in a black market: inequalities in access to land rose, and conflicts among family members over inheritance increased dramatically, along with disputes over land. Worth noting is the fact that "many land parcels were sold under distress conditions and purchased by people with regular non agricultural income"(André and Platteau 1998: 28), which shows that those who did not have the possibility to earn additional sources of income fell into a sort of poverty trap: by selling their land they lost the ability to get out of poverty. In addition this black or grey form of buying and selling land implied the erosion of traditions and customary rules, because, as a good, it became independent of such notions. Thus, one can see that scarcities in resources have tended to magnify inequalities through (illegal) market operations.

Rwanda has been characterized by a strong authoritarian tradition coupled with the clan organization of power (Prunier 1995). The key people surrounding President Habyarimana (whose assassination is considered to have set in motion the genocide) were all members of the same clan or belonged to the same region (Prunier 1995).

The organizers of the coup d'état formed a small group belonging to the regime's political, military, and economic elite, who had once been close to the president and whose goal was to stop democratization (Prunier 1995). While they benefited from the involvement of the Presidential Guard – to the extent that it provided a highly organized group capable of targeting selected individuals and groupings – it is clear that the main agents of the genocide were the peasants themselves. As Prunier puts it, "their [the organizers'] efficiency in carrying out the killings proves that these had been planned well in advance . . . but it would not have been enough had it not been for two other factors: the capacity to recruit fairly large numbers of people as actual killers and the moral support and approbation of a large segment – possibly a majority of the population." Thus, the costs of organizing and sustaining an uprising had been considerably reduced by:

(1) the scarcities of land and opportunities of off-farm income; and (2) discursive strategies that served to mobilize high numbers of poor, unemployed and uneducated young men without any prospect of inheriting land. The capacity of the state to address the demands for relief coming from the bottom of society was low, since per capita gross domestic product (GDP) fell by 34 percent between 1986–90 and 1994–98, whereas the price of food rose by 21.49 percent in 1994–98. It should be noted that the prize coveted by the plotters was political power, whereas peasants acted out of strong grievances: "all these people who were about to be killed had land and at times cows. And somebody had to get these lands and these cows after the owners' death" (Prunier 1995). Hence, the issue of ethnicity should be considered more as an instrument in the hands of decision-makers than a cause of the conflict. The underlying and ultimate reason is more likely to be found in the combination of resource scarcities and declining state power. Indeed, one should note that the Hutu and Tutsi are not tribes but social groups inside the same culture (Prunier 1995). This had allowed mixed marriages and prevented the separation of dwellings. Thus, people had lived together and side by side all the time. The fact that "intra-ethnic" killings nevertheless took place is an indicator of the political (as opposed to ethnic) feature of the crisis.

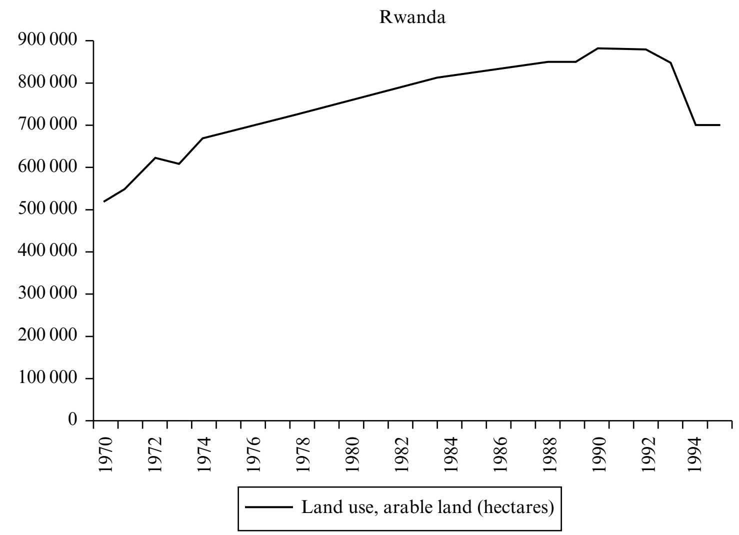
SIMULATING THE CONFLICT AND GENOCIDE

To summarize the scenario suggested by this historical narrative, we can say that the conditions set up at independence led to expectations of increased land availability either through appropriations from minority groups or through gain from marsh draining and deforestation. As a result, birth rates exploded and a demographic expansion took place. These trends are illustrated in the following graphs. Firstly, Figure 7.3 shows the increase in available arable land as the Rwandan government cleared marshes and forests to expand the total area. However this expansion comes to an end in the late 1980s and even a decline starts taking place in the early 1990s.

The demographic expansion is visible from Figures 7.4 and 7.5 which show population increase as well as the persistence of a high population growth rate until 1994.

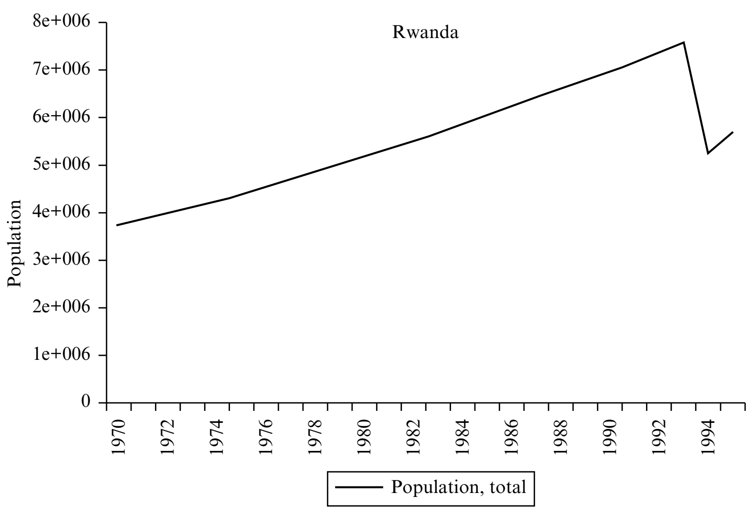
A last illustration of these trends can be presented in the form of the population density of rural areas which also increases considerably from 1970 on (Figure 7.6).

Given these trends and the kinds of incentives that prevail, land resources are eventually all used up and a violent confrontation between two competing groups, which can be described in terms of Lanchester



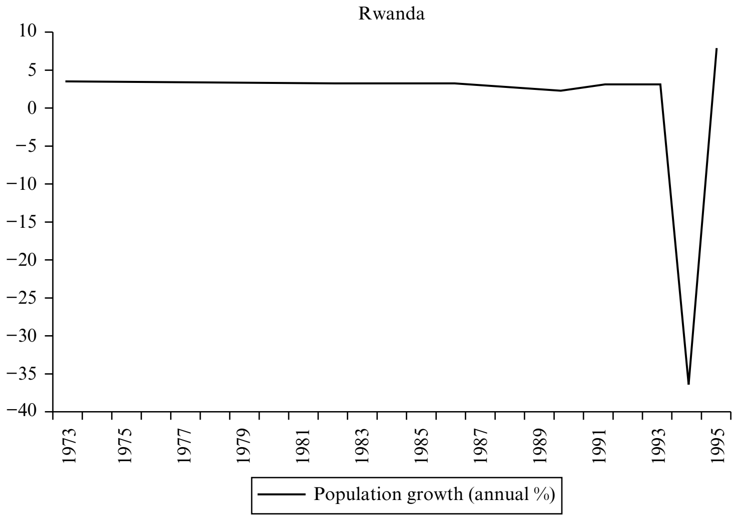
Source: World Bank.

Figure 7.3 Total arable land surface in Rwanda



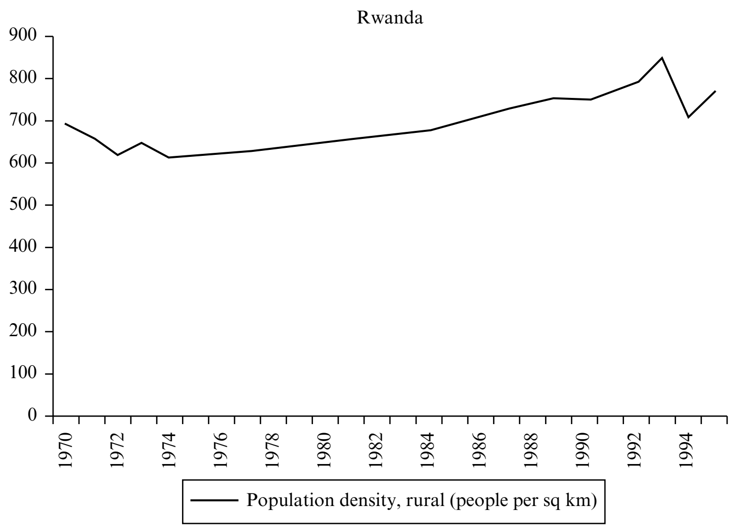
Source: World Bank.

Figure 7.4 Population expansion in Rwanda, 1970–1995



Source: World Bank.

Figure 7.5 Population growth rate in Rwanda, 1970–95



Source: World Bank.

Figure 7.6 Population density in rural areas, Rwanda 1970–1995 combat equations, will start. The work presented here is not the first to use Lanchester relations to simulate the situation in Rwanda, from about 1990 when fighting between (mostly) Tutsi rebels and (mostly) Hutu Rwandan government troops[25] intensified, to 1994 to 1995 when the Rwandan genocide took place.[26]

In contrast to other attempts, our work relies on the considerations introduced by Deitchman (1962) in an article that develops a theory of the application of the Lanchester relations to guerrilla warfare. In his theory of combat, Lanchester evoked the two already discussed notions of concentrated and dispersed fighting. Deitchman (1962) presents the strategic situation of guerrilla fighters in the following way. The guerrillas are usually dispersed over a territory which forces government or occupying forces to attack them in a dispersed way, for instance by blanketing a whole region with search-and-destroy missions, artillery fire, or even massive bombings. Guerrilla forces on the other hand can attack targeted governmental or occupying forces in a concentrated way, which they do mostly by using ambushes. In addition, guerrilla fighters depend largely for their survival and the continuation of their efforts on the existence of a part of a population that supports them and provides them with a base for recruitment purposes. There is thus a fundamental asymmetry between the guerrillas, who fight in a concentrated way, and the government or occupying troops that have to undertake dispersed combat operations. This situation has two important consequences. On the one hand, being forced to fight in a dispersed manner, government or occupying forces will inevitably hit civilians who have nothing to do with the guerillas, and exert some form of "collective punishment." This will often turn the population that the guerrillas claim to represent even more against the government or the occupier.[27] Another way to weaken guerrilla forces is to shrink the fraction of the population that supports them through violent action up to and including genocide. Such behavior aims either at intimidating and scaring the population close to the rebels and eventually when the genocide stage is reached to diminish the size of the group who might join guerrilla forces. What might trigger such extreme actions? In our view essentially the fear that otherwise rebel groups will get even stronger and take power. We can thus establish the following assumptions for our combat and "Genocide" scenario.

The Rwanda situation can be described as a typical Deitchman guerrilla combat model where Tutsi rebels are dispersed but fight the government troops in a concentrated fashion through ambushes. They recruit from about 10 percent of the total Rwandan Tutsi population (estimated at about 650 000 in 1990 as opposed to 6 800 000 Hutus). Their initial size is estimated from various sources, especially Jermann et al. (1999), at 5000 in the beginning of 1990. Government troops (mostly Hutus) are estimated at 40 000 and recruitment possibilities for them at about 100 men per week. Tutsi rebels can inflict much heavier losses on government troops than vice versa.

The following scenario may be envisaged from 1990 on, consistent with our earlier narratives. The resource crisis due to the overall population expansion leads the (Hutu-based) government of President Juvenal Habyrimana to put more pressure on Tutsi-controlled land. This leads to an increase in recruits for the Tutsi rebel army which grows rapidly in size. Given the heavy losses this force can inflict upon government troops, parity with the Hutu forces is reached at the end of 1992 and Tutsi fighters continue to deplete them and achieve superiority. Maximum superiority is achieved for Tutsi forces in the spring of 1994. This can be considered in a way as a triggering event for the genocide of the Tutsis and moderate Hutus, which begins in April 1994. In other words, it is assumed here that what triggers the genocide is an attempt on the part of government forces to reduce their differential with the Tutsi fighters. In that sense, the bombing of Rwanda's President Habyarimana's plane on April 6, the apparent triggering event, manifested (whether it was due to Tutsis or extremist Hutus is still unclear) the weakness and loss of control at the top. This then, in the view of Hutu extremist and government forces, called for drastic action to reduce the recruitment base of the Tutsi fighters.

Based upon these assumptions, the following Lanchester-type relations can be set up:

$$\frac{dtutsif}{dt} = par1pottr - par2\, gov\, tutsif$$

$$\frac{dgov}{dt} = -\, par3\, tutsif + par4$$

$$\frac{dpott}{dt} = par5pott - par6\, par7\, govpott$$ [28]

$$pottr = 0.1pott$$

$$par6 = 1\ if\ (par8gov - tutsif) < 0$$

$$0\ otherwise$$

where *tutsif* stands for Tutsi fighters, *gov* for government forces, *pott* for Tutsi population, *pottr* for recruitment base from Tutsi population. *par*1 . . . *par*8 represent various constant parameters. Three of these deserve further explanation: *par*4 represents the drafting of 100 people per week by the government army which was initially trained and supplied by French forces present in the country; *par*5 is the rate of increase of the Rwandan population which can be calculated from demographic data up to 1994; *par*6 represents a logical (Boolean) variable with value 1 when the critical differential mentioned above, between government forces and Tutsi fighters, is reached and 0 otherwise. This critical value has been estimated on empirical grounds at the point when Tutsi fighters are equivalent in numbers to 2.5 government forces. *par*6 represents in some sense the "genocide" parameter.

One can notice that the above differential equations constitute a "typical" Deitchman asymmetric form of the original Lanchester equations with reinforcements where the guerilla (Tutsi) fighters are attacked by government troops in a dispersed way whereas Tutsi forces fight in a concentrated fashion. This relatively simple model gives then the following results expressed in graphical form in Figure 7.7.

It has to be pointed out here that reliable combat data for Rwanda are extremely difficult to get. In particular, a monthly evolution of the number of fighters is practically impossible to evaluate. Nevertheless, the swiftness

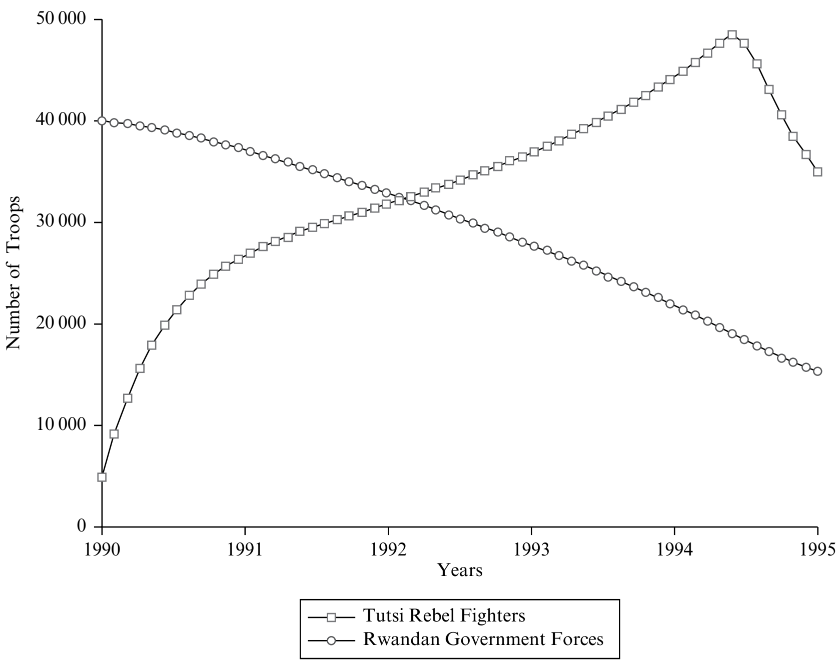


Figure 7.7 Evolution of numbers of Tutsi rebels and Rwandan government forces

of the Tutsi rebel response after the start of the genocide suggests a relatively effective and superior military force to which allies from Uganda, Burundi and the Congo might have contributed. This conclusion derives from our model and is represented in the graph of Figure 7.7. One should also notice that the 2.5:1 superiority of the Tutsis which triggers the genocide is close to a 3 to 1 ratio which traditional analysts link to a victorious outcome for the force that achieves it. Despite the genocide (and maybe because of it) Tutsi superiority is still there at the end of 1994, explaining ultimate Tutsi victory and conquest of power.

Some reliable data exists only for the pace of the genocide and its final magnitude of about 500 000 people. Figure 7.8 represents what we can reproduce here solely with the help of our model and without any ad hoc assumption based upon exogenous factors. However more empirical investigations will have to be carried out as more data becomes available.

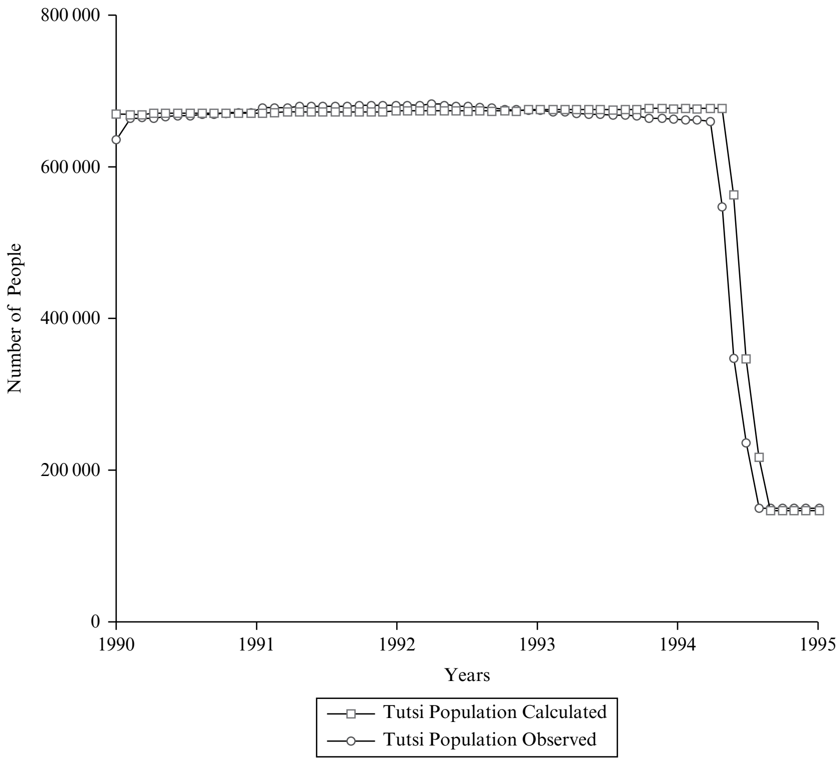


Figure 7.8 The Rwandan genocide: Tutsi population calculated and observed

CONCLUSION

We have tried here to shed some light on the complex linkages between environmental conditions and trends and the issue of conflict. Through an analysis of some basic aspects of the relationships between natural resources, demography and institutions and an analysis of the existing literature, the Homer–Dixon hypothesis of a direct causal linkage between environmental scarcities and conflict was rejected. However, the importance of crucial institutional settings was emphasized. The "political tragedy" affects the "economic tragedy" through the negative impact of conflict on property rights protection, which can lead to overexploitation. The economic tragedy is enhanced by the "demographic tragedy" which is also due to the absence of well-defined property rights and contract enforcement. The economic "tragedy of the commons" influences the risk of conflict through the externality losses from resource extraction. As in the case of mineral resources such as diamonds or oil, the potential short- and medium-run gains of extraction are immense, but the externality losses are small because exclusion is possible. Such goods make it profitable for the elite to launch and then stick to a suboptimal "warlordism" production method. For non-exclusive and renewable resources such as tropical wood or fish, the main problem is overuse. These goods, however, do not appear to have such a harmful impact on political conflict, with the exception of situations like Rwanda where land distribution itself becomes a major issue. Because the main problem in the end is not environmental but institutional, mostly institutional strategies and policies should have the biggest effect in the avoidance of outcomes where environmental scarcities, together with demographic expansion and crowding, lead to violence and warlord-dominated societies. This does not take away from the importance of technical improvements to agriculture such as the development of more drought-resistant crops or the building of dikes and levees as well as of reservoirs, both to prevent floods and to store water, in order to ensure agricultural productivity at a high level despite climate change. The biggest task however is to maintain cooperation and prevent conflict in societies most vulnerable to change. This requires specific policy measures such as worldwide agricultural liberalization to enhance the value of farm-produced output and to encourage the institution and protection of well-defined property rights. In addition such measures as cartel encouragement for scarce and valued natural resources, protection of existing property rights, reduction of the costs of agricultural and industrial production in the developing and organizing of embargoes against warlord-type production can help set societies on the path of the rule of law. These are formidable but not insurmountable tasks, especially if they are undertaken on the basis of a large consensus by democratic industrialized states.

Above all, it is necessary in the future to identify, so that they may be avoided, the positive feedback mechanisms triggered by environmental scarcities that can come about either from an increase in population or the overuse of resources. These are the mechanisms that can lead to major conflicts within and between societies and that should be curtailed. We have been trying to present here some of the empirical analyses and methodologies that could make, in addition to the theoretical considerations we outlined above, these trends toward positive feedback mechanisms more identifiable.

NOTES

1. The S curve analysis and its application to conflict has been initiated by Dacey (1998; Dacey and Gallant 1997). The formulation used here for the critical risk ratio is based on losses, whereas the formulation used in Dacey is based on gains. These formulations are logically equivalent.
2. In other words, one can never completely substitute private goods for collective goods, and vice versa.
3. For example, the Carthaginians before Hannibal and the Romans in the late stages of the Western Empire were racketed by mercenaries as a result of political turmoil and the decline of the state and imperial organization.
4. One should here remember that Pareto optimality does not mean equity. Pareto optimality can result in a very unequal distribution of power and wealth in a society.
5. Dasgupta and Heal (1979: 54) point out two cases where tax equilibria exist whereas Lindahl equilibria do not. Moreover, the two equilibria are equivalent only if institutional costs are zero, a most unlikely situation.
6. Tilly in particular, emphasizes this point.
7. This point is made by Pirenne (1980 [1937]): the reduction in taxable trade, both domestic and international, due to the Moslem conquests and raids on the Mediterranean coastline brought the Frankish Merovingian Dynasty down and resulted in the new Carolingian dynasty. Further invasions and transaction reductions signaled the quick end of this new dynasty and its replacement by Western European feudalism.
8. After the British economist Alfred Pigou (1932).
9. If $t < 0$, the subsidy is in fact a tax and if $\tau < 0$, the lump sum tax becomes a subsidy.
10. For an alternative treatment see Skaperdas and Syropoulos (1996).
11. The concept which we call "fighting" in the present contribution is similar (and can be regarded as interchangeable) to the one of "appropriative activities," as it is sometimes called in the conflict literature.
12. It would surely also have been interesting to focus on learning issues in a dynamic framework, or to put more emphasis on the interaction between the different agents. However, in the present contribution the emphasis is put on the link between natural resources and the fighting–producing decision.
13. As opposed to the previous utility function which referred to the choice between public and private goods, this one refers to the choice between fighting and producing and is thus labeled u_{pf}. The two utility functions are obviously linked, a fact that we will invoke below.
14. The framework of the constraint is inspired by Dasgupta and Heal's (1979) similar reasoning for the case of public goods.
15. We can see from this budget constraint how we could overcome the restriction posed in Assumption 6 and make our model necessary and sufficient for the explanation of warlord activities: the warlord is the one who organizes the taxation of resources to distribute the initial subsidy to fighters.

16. Empirical cases of such international cartels include the OPEC or the coffee cartel until the 1990s.
17. A sad exception is Angola.
18. Following a "rational choice" approach, we do not consider factors like social norms and conventions.
19. This is due to the particular shape of the output curve and the slope of the cost curve. A continuation of increasing returns after A is perfectly conceivable for a while even if the assumption of the S-shaped output curve is maintained.
20. This general formulation is due to Dasgupta and Heal (1979: 122, 134). Obviously if taxes corresponding to the scarcity rent of the resource and an "entry" fee to start using it are charged then the problem of overuse disappears. The dynamics of equations (7.36) and (7.37) are represented more explicitly in an article by Brander and Taylor (1998) describing sustainability problems on Easter Island over time. They exhibit a long-term (low-frequency) population resource cycle analogous to those suggested by Volterra (1931), Lotka (1925) or Kostizin (1937) for animal populations.
21. We refer again to Brander and Taylor (1998).
22. The purpose of this short comment is not to go through the complex process which led to the genocide. It rather aims at highlighting the influence of land scarcities and population growth on the emergence of the conflict.
23. As emphasized by André and Platteau (1998), most studies focus on productivity issues while neglecting the social impacts of the commercialization of agriculture.
24. One can reasonably generalize the findings of the study since the area under consideration, as one of the largest and most important, was particularly involved in the outburst of violence in 1994.
25. We are perfectly aware of the fact that both the rebels and the victims of the genocide included also so-called moderate Hutus, something that the literature we cite also points out. For the sake of convenience we will however refer to the rebels and victims as Tutsis and the government troops and killers as Hutus.
26. Work done by Jermann et al. (1999: 132–136) constitutes a first attempt to use this technique. However, their representation of the combat interaction is based on very ad hoc formulations driven by particular events which weaken the theoretical coherence of the Lanchester relations that they use without achieving a better rendition of actual events. Nevertheless their work is useful in providing an initial framework and some basic data.
27. On the other hand, if the population attributes the blame to the guerrillas, the government's popularity could then increase.
28. This whole system was simulated with the help of the SPARE dynamic simulation package developed at the Graduate Institute of International Studies, Geneva.

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APPENDIX 7.1 INHERITANCE AND DEMOGRAPHY IN THE SWISS ALPS, BY ELLEN WIEGANDT: STUDIES OF A SWISS AGRARIAN ALPINE COMMUNITY IN THE NINETEENTH CENTURY

Table 7A.1 Family size and wealth

	< 2% total wealth	> 2% total wealth	
Families < 4 children	23	6	29
Families > 4 children	8	18	26
	31	24	

Note: Yule's Q = 0.792 χ^2 Significance < 0.001.

Source: Weigandt (1977).

Table 7A.2 Regression of father's wealth – son's wealth as determined by father's wealth:regression summary

Degrees of freedom	R	R square
86	−0.75	0.56

Source: Weigandt (1977).

Table 7A.3 Regression of father's wealth – son's wealth as determined by father's wealth:coefficients

	Estimated value	Standard error	T value	Significance
Constant	1.07	0.19	5.75	< 0.0001
Father's wealth	−0.79	0.08	−10.42	< 0.0001

Source: Weigandt (1977).

APPENDIX 7.2 REGRESSION FOR ALL COUNTRIES THAT HAVE A MOSLEM POPULATION, BY RANA CREVIER

Table 7A.4 Model summary

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.849[a]	0.721	0.511	0.738

Note: a. Predictors: (Constant), unemployment rate FEMALE, GDP per capita (USD) 2003, total fertility rate, 2000-2005, percentage of population that belongs to any Islamic sect, school life expectancy (expected # of years of formal schooling)-FEMALES, PERCMEN

Source: Crevier (2005).

Table 7A.5 ANOVA[b]

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	11.240	6	1.873	3.438	0.055[a]
Residual	4.360	8	0.545		
Total	15.600	14			

Notes:

a. Predictors: (Constant), unemployment rate FEMALE, GDP per capita (USD) 2003, total fertility rate, 2000-2005, percentage of population that belongs to any Islamic sect, school life expectancy (expected # of years of formal schooling)-FEMALES, PERCMEN

b. Dependent Variable: my freedom index

Source: Crevier (2005).

Table 7A.6 Coefficients[a]

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	14.557	6.124	0.885	2.377	0.045
percentage of population that belongs to any Islamic sect	5.425E-02	0.017		3.275	0.011
PERCMEN	–0.443	0.139	–1.763	–3.186	0.013
total fertility rate, 2000–2005	0.795	0.230	0.925	3.461	0.009
school life expectancy (expected # of years of formal	0.501	0.149	1.188	3.356	0.010
schooling)-FEMALES GDP per capita (USD) 2003	1.426E-04	0.000	1.211	2.437	0.041
unemployment rate FEMALE	–4.19E-02	0.027	–0.295	–1.532	0.164

Note: a. Dependent variable: my freedom index.

Source: Crevier (2005).

APPENDIX 7.3 RESULTS OF REGRESSIONS BETWEEN A VARIETY OF DENSITY VARIABLES AND INTERNAL STRIFE AS MEASURED BY THE UPSALA–PRIO DATASET, BY SÉBASTIEN DI IORIO

The results from our statistical model tend to support the claim that resource scarcities – as measured by population density relative to the productive surface – have an influence on the risk of armed conflict. The coefficient of this variable has a Wald statistic equal to 4.617 which is significant at the 0.05 level (95 percent confidence level). The whole model is significant at the 0.01 level according to the model Chi-square statistic. We see a positive relationship between population density and the risk of conflict, a unit increase in this variable produces a 1.091 increase in odds of conflict to occur. In this model, agriculture value added (that is, productivity of the agricultural sector) is not very robust but scores better in explaining conflict onset than gross domestic product (GDP) growth.

Table 7A.7 Variables in the equation

		B	S.E.	Wald	ddl	Signif.	Exp(B)
Etap 1(a)	Population_density_rural_people_per_sq#_km_of_arable_land	0.087	0.041	4.617	1	0.032	1.091
	Agriculture_value_added_per_worker_constant_1995_US$	−0.086	0.051	2.838	1	0.092	0.918
	GDP_growth_annual	0.042	0.060	0.475	1	0.491	1.043
	Constant	−46.679	22.461	4.319	1	0.038	.000

Notes:
a. Variable(s) entered at etap 1: Population_density_rural_people_per_sq#_km_of_arable_land, Agriculture_value_added_per_worker_constant_1995_US$, GDP_growth_annual.
B is the estimated coefficient with standard error S.E., the ratio of B to S.E., squared, equals the Wald statistic. If the Wald statistic is significant (i.e., less than 0.05) then the parameter is useful to the model. Sig is the significance level of the coefficient and Exp(B) is the "odds ratio" of the individual coefficient.

Source: Sébastien di Iorio (2005 data set).

The conclusions we can draw from these preliminary results tend to support the "demographic pressure" argument which, simply put, addresses armed conflicts by looking at demographic and environmental indicators rather than economic or political regime types of parameters. However, these results are not fully robust and need to be taken with great care since refinements of the model are clearly needed in order to put forward definitive claims.