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Resource Conflict in Vulnerable Environments: Three Models Applied to Darfur

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Abstract

A recurring argument in the global debate is that climate deterioration is likely to make social conflicts over dwindling natural resources more common in the future. In this paper, we present a modelling framework featuring three potential mechanisms for how the allocation and dynamics of scarce renewable resources like land might cause social conflict in vulnerable environments. The first model shows how decreasing resources make cooperative trade between two groups collapse. The second mechanism introduces a Malthusian subsistence level below which disenfranchised members of one community start to prey on the resources of another community in an appropriative conflict-setting. The third scenario explores how the long-run dynamics of resources and population levels interact to cause cycles of stagnation and recovery. Predictions from the models are then applied to the ongoing conflict in the Darfur region of Sudan. Our analysis suggests that effective resources per capita in the region appear to have declined by about 5/6 since the 1970s, which at least partially explains the observed disintegration of markets, the recent intensity of conflicts, and the current depopulation of large parts of Darfur.

Key words: Market integration, resource conflict, vulnerable environments, appropriative conflict, long-run resource and population dynamics, Darfur

JEL Classification codes: P16, O41

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> "Almost invariably, we discuss Darfur in a convenient military and political shorthand - an ethnic conflict pitting Arab militias against black rebels and farmers. Look at the roots, though, and you discover a more complex dynamic. Amid the diverse social and political causes, the Darfur conflict began as an ecological crisis, arising at least in part from climate change."
> UN Secretary General Ban Ki Moon, *Washington Post*, June 2007.

1 Introduction

In the literature on the 'curse of natural resources', there has been a focus on the adverse effects of the prevalence of valuable minerals like diamonds and oil. It has been argued that an abundance of this type of resources easily leads to rent seeking and more or less violent appropriative conflicts involving government agents and loot-seeking rebel groups. It has also been shown that a strong institutional environment can mitigate the supposedly negative effects of natural resource wealth (Collier and Hoeffler, 2004; Mehlum et al, 2006).

It is less clear, however, how the division of more basic, renewable natural resources like water and land - that are used in the every-day production of the average farmer in developing countries – might influence the political economy of regions and ethnic groups. Rather than giving rise to loot-seeking struggles based on greed, it has been suggested instead that an increased scarcity of this type of resources might lead to conflict. Recent climate change has been identified as a factor that might increase the prevalence of such scarcity-induced conflicts in the future (Schubert et al, 2008; Diamond, 2005; Homer-Dixon, 1991, 1994). The theoretical underpinnings of this "neo-Malthusian" hypothesis of conflict are however very vague. The line of argument has further been criticized by scholars on international security who argue that systematic statistical research using cross-country panel data has so far largely failed to find any significant link between civil conflicts and environmental stress (Urdal, 2005; Nordås and Gleditsch, 2007).

Our purpose is not to take sides in this debate. The broad aim of this paper is rather to develop a theoretical framework for how scarcity of basic resources like land might potentially induce conflict in vulnerable environments.[1] We present three models of resource conflict: The *market integration model*, the *appropriative conflict model*, and the *long-run resources and population model*. The framework describes a gradually intensified conflict scenario and an analysis that moves from the short-run micro to the long-run macro level.

The first model outlines an ancient resource allocation problem between a farming and a herding community which can either share land equally in a cooperative market solution, or in a non-cooperative bargaining game. In the appropriative conflict model, one of the two communities is assumed to fall below a Malthusian subsistence level, which induces their least socially integrated members to start a predatory struggle aimed at capturing the other community's resources. In the third model, we consider the long-run dynamics of resources and population on the macro level in a Ricardo-Malthusian model in the spirit of Brander and Taylor (1998).

It is shown that a fall in effective resources or in resources per capita - perhaps due to climate change - might gradually intensify conflict by i) causing market integration to collapse, ii) by pushing the poorest segments of the population into an appropriative struggle, and iii) by initiating devastating long-run cycles of stagnation of resources and population.

When some of the implications from the models are applied to a case study of the Darfur region in Sudan, we find that effective land resources per capita appear to have diminished by about 5/6 since 1973, which in turn should have had an impact on the observed disintegration of a market-like economy, on the onset of appropriative conflicts from the 1980s, and on the current wave of mass killings and depopulation of large areas of Darfur. The model, as well as recent experiences from Rwanda, seem to suggest however that the ongoing disaster might eventually turn into a relatively peaceful period with growing resources and populations, though with a lower long-run equilibrium.

The theoretical part as well as the empirical part is related to a number of existing works. The market integration model is similar in spirit to Dalgaard and Olsson (2007). However, in that paper, the model is primarily exploited to discuss how market integration in the Western world eventually prevailed

[1] We define a vulnerable environment as one where people have a production structure with a great deal of dependency on natural factors such as rainfall and temperature and where people live close to some minimum subsistence level.

over non-cooperative bargaining as a result of human capital accumulation.

Several other articles also deal with farmer-herder conflicts in the Sahel. Van den Brink et al (1995) analyze theoretically the efficiency of exclusionary property rights to land in an environment where herders naturally have a preference for institutions that allow for flexible adjustments if rains should fail. Turner (2004) provides an overview of the political ecology literature in relation to farmer-herder relations in the Sahel.

The appropriative conflict model between farmers and herders uses the same contest success function as in the conflict literature, but introduces scarcity as a "trigger" of fighting rather than resource abundance.[2] The only other model that we know of that makes a similar attempt is Grossman and Mendoza (2003) where fighting is also carried out for survival. The least novel modelling setup in our paper is the third long-run model which borrows most of the setting from Brander and Taylor (1998) and related works such as Maxwell and Reuveny (2000).

We thus believe that our paper makes the following broad contribution to the literature: Firstly, it offers a general modelling framework for analyzing resource scarcity and conflict in vulnerable environments. Second, it provides a new model of how resources per capita might affect market integration, and a new variant of the existing appropriative conflict-framework. Thirdly, it is the first systematic conflict modelling exercise that is applied to the Darfur crisis.

The paper is structured as follows: The market integration model is presented in section two, whereas the appopriative conflict model and the long-run model are laid out in sections three and four. Section five contains the case study on Darfur. Section six concludes.

2 Market integration

In this first model, showing how resources affect market integration, let us consider an economy with two population groups that each consume two essential goods. For simplicity, we might think of the population groups as being *farmers* (denoted f) and *herders* (denoted h). Farmers have a comparative advantage (defined below) in producing *crops* whereas herders have a comparative advantage in producing *meat*. Both farmers and herders

[2] See for instance Grossman and Kim (1995) and Olsson (2007).

need, however, to consume both crops and meat. Both activities further require a rival natural resource with weakly defined property rights; in the case at hand *land*.

There are two basic choices to be made. Firstly, farmers and herders need to decide how much meat and crops they should produce within their group. There are two possible regimes: Either that both groups produce both goods in autarky so that farmers also keep some cows and herders grow some crops, or that both groups specialize in the production in which they have a comparative advantage and then trade goods with the other group in a open market economy.

The second key choice is how the two groups should divide the land between them.[3] We assume to start with that the resource allocation is determined in a Nash bargaining process. Even here, there are two potential outcomes: The two groups can either grab as much as they can of the resource through political strength or brute force or they can engage in specialized production and peaceful trade, in which case the resource will be divided in a cooperative manner.

The sequence of events in this model is the following:

1. The two groups choose what regime they prefer to be in: Non-cooperative bargaining in autarky or cooperative bargaining with a market exchange of goods.

2. The groups allocate the common natural resource (R) through the political regime chosen in the first stage.

3. The two groups decide how much to produce and consume (and potentially trade), using the allocation of R determined in the second stage.

We assume rational individuals who can perfectly assess the effects of choices in each stage. The model is solved through backward induction. We therefore start below by solving for the production and consumption decisions in the third stage.

[3]As analyzed by van den Brink et al (1995), it is not obvious that herders actually want to have exclusionary property rights to a certain piece of land given their nomadic way of life. However, for the model to be relevant, it is enough that one of the groups (the farmers) will try to establish exclusive possession to land.

2.1 Preferences and production

There are L_f adults in the farming community and L_h adults in the herding community so that $L = L_f + L_h$. For the moment, let us assume that there is no mobility between communities.

Individuals in population group $i = f, h$ have the following Cobb-Douglas utility function:

$$U_i = U(f_i, h_i) = f_i^{1/2} h_i^{1/2}, \ i = f, h \tag{1}$$

Utility is gained in both regions from consuming positive amounts of crops f_i and meat h_i. Since the exponents have no interesting interpretation in our model, we simply normalize them to be 1/2, which also implies homogeneity of degree 1. The utility function satisfies the usual assumptions of a positive but diminishing marginal utility of each product.

All individuals in the two groups have 1 unit of time at their disposal for productive activities during adulthood. In a regime where the two groups produce in autarky, they will split their time between production of the two goods. Accordingly, individuals are then subject to a time constraint

$$1 = x_{fi} + x_{hi}, \tag{2}$$

where x_{fi} represents time allocated to farming in community i.

The production technologies for the representative producer in the two groups are

$$F_i(R_i/L_i, x_{fi}) = (R_i/L_i)^{\alpha_i} x_{fi}^{\gamma} \tag{3}$$

$$H_i(R_i/L_i, x_{hi}) = (R_i/L_i)^{\beta_i} x_{hi}^{\delta}, \tag{4}$$

respectively. Since we want to keep the model as simple as possible, output is only a function of resources per capita and work effort.[4]

R_i is to be thought of as the amount of land that can be used in both tasks in a given community and L_i is the total (working) population in group i. Land is assumed to be shared equally within each community so that each person gets R_i/L_i, but it is a rival factor of production between communities. As will be discussed further below, $R_f + R_h = R$ where R is the fixed effective supply of land, reflecting both size and quality. In other

[4] In Dalgaard and Olsson (2007), we also included human capital that accumulated over time through learning-by-doing. Since that is not the focus of this work, we refrain from using either human capital or productivity parameters here.

setups, we might instead think of R as for instance water, forest resources, or indeed as an ecological complex of renewable resources that are used directly in production.

The source of comparative advantage is that in the farming community, one extra unit of land per worker has a higher output elasticity than one extra unit in herding, whereas in the herding community, an extra acre of herding land has a higher output elasticity than in farming:

$$0 < \alpha_h = \beta_f < \alpha_f = \beta_h < 1 \tag{5}$$

For simplicity, we assume that there is a symmetry in these productivity differences so that $\alpha_f = \beta_h$ and $\alpha_h = \beta_f$. There is, however, always diminishing marginal returns to land. The elasticities of work effort x in farming and herding, γ and δ, are assumed to be identical in the two communities and have a level of γ,$\delta \in (0, 1)$.

2.2 Optimization in autarky

As discussed above, there are two basic regimes for organizing production: Autarky in which the two groups produce both goods in isolation from each other, and a market economy where trade between groups takes place and production is specialized.

In autarky, the optimization problem is to find, for both groups $i = f, h$, the time allocations x_{fi} and x_{hi} that maximize utility U_i in (1), subject to the constraint that $1 = x_{fi} + x_{hi}$. The straightforward solutions for the time allocation problem turn out to be

$$x^*_{fi} = \frac{\gamma}{\gamma + \delta}, \quad x^*_{hi} = \frac{\delta}{\gamma + \delta}, \text{ for } i = f, h.$$

The indirect utility in autarky (with an index a) is therefore:

$$V_i^a \equiv \sqrt{\chi \left(R_i / L_i\right)^{\alpha_i + \beta_i}}. \tag{6}$$

where $\chi = \frac{\gamma^\gamma \delta^\delta}{(\gamma+\delta)^{(\gamma+\delta)}}$.

2.3 Optimization in the market economy

In the market regime, people specialize in production in accordance with their comparative advantages, implying of course that farmers only produce crops and that herders only produce meat.[5] While individual preferences are the same as in autarky, the budget constraints are different. For individuals in for instance community $i = f$, total income (y_f) is divided between consumption of crops (f_f) and meat (h_f):

$$y_f = f_f + ph_f, \tag{7}$$

where p is the relative price of meat, i.e. measured in terms of crops.

Farmers' income derives from using their entire time endowment on production of crops so that $x_{ff} = 1$.[6] This means that total income is simply

$$y_f = (R_f/L_f)^{\alpha_f}. \tag{8}$$

In a corresponding manner, herders will specialize in herding and their relevant constraints are

$$y_h = p\,(R_h/L_h)^{\beta_h} = f_h + ph_h.$$

Solving the utility maximization problem of individuals in the two communities leads to the following demand equations for the two products:

$$f_i^d = \frac{y_i}{2},\ h_i^d = \frac{y_i}{2p},\ \text{for } i = f, h. \tag{9}$$

In a competitive equilibrium, total relative supply (left-hand side) must equal relative demand (right-hand side), and the price adjusts so as to clear markets:

$$\frac{(R_f/L_f)^{\alpha_f} L_f}{(R_h/L_h)^{\beta_h} L_h} = \frac{\frac{1}{2}[y_f L_f + y_h L_h]}{\frac{1}{2p}[y_f L_f + y_h L_h]}. \tag{10}$$

In this expression, $y_f L_f$ is total income of the farming community whereas

[5] This is not usually observed in reality since even trading farming communities usually keep some cattle as a kind of insurance policy. We use the extreme specialization assumption since it simplifies the analysis.

[6] Recall that violent conflict is not an option in this regime since we regard it as too unlikely that people in the two regions would first go to war over R and then trade peacefully with each other.

$y_h L_h$ the total income of the group of herders.

Since the right-hand side of (10) collapses into just p, and since $\alpha_f = \beta_h$ by (5), we can derive the equilibrium relative market price of meat to be:

$$p^* = \left(\frac{L_f}{L_h}\right)^{1-\alpha_f} \left(\frac{R_f}{R_h}\right)^{\alpha_f} \tag{11}$$

A key feature of this expression is that in the market economy, attempts by for instance farmers to get a larger share of total land - i.e. an increase in the R_f/R_h-ratio - will cause a higher supply of crops but also a lower aggregate supply of meat. This, in turn, will increase the relative price of meat, as shown in (11). Since farmers also eat meat, they will be hurt by the price increase. We can thus get a sense of how the market institution will typically reduce incentives for engaging in an appropriative struggle for basic natural resources. The relative price will also be affected by the population ratio L_f/L_h.

As in the previous section, we can now solve for the indirect levels of utility in the market economy:

$$V_f^m = f_f^{1/2} h_f^{1/2} = \sqrt{\frac{(R_f R_h)^{\alpha_f}}{4} \frac{L_h^{1-\beta_h}}{L_f^{1+\alpha_f}}} \tag{12}$$

$$V_h^m = \sqrt{\frac{(R_h R_f)^{\beta_h}}{4} \frac{L_f^{1-\alpha_f}}{L_h^{1+\beta_h}}} \tag{13}$$

From these expressions, it is clear that the utility of, for instance, farmers will be directly dependent not only on not only their own resource levels, but also on the corresponding level for the herders (R_h). This is the primary reason for the emergence of a more cooperative political process, as described below.

2.4 Resource allocation through bargaining

In this second stage of the model, farmers and herders divide up the resource stock in a political bargaining process. We assume that this process can be described as a Nash bargaining scenario that is in place both during autarky and the market economy:

$$\max_{R_f,R_h} W^z = \left(V_f^z\right)^{\pi} \left(V_h^z\right)^{1-\pi}, \ z = a, m \tag{14}$$

As will be shown, the relative bargaining strength $\pi \in (0, 1)$ will play a key role for the outcome of the process. π might be thought of as capturing crude political strength, perhaps based on military advantage, government support, higher levels of education, or historical reasons.

In autarky, substitutions of indirect utility levels in (6) and the identity $R_h = R - R_f$ into (14) gives us a maximization problem with the straightforward solutions:

$$R_f^{a,*} = \pi R; \quad R_h^{a,*} = (1-\pi) R.$$

In other words, the division of the resource will be uncooperative and only reflect bargaining strengths π and $1 - \pi$. The obvious reason is the absence of any interdependence between the two groups due to the lack of trade.

If the two groups specialize and trade in a market economy, however, we can infer from inspection of (12) and (13) that the Nash bargaining solution simply boils down to being the allocation that maximizes $R_f (R - R_f)$, which is obviously

$$R_f^{m,*} = R_h^{m,*} = \frac{R}{2}.$$

Thus, regardless of bargaining strengths, farmers and herders will agree to share the resource equally because this arrangement will maximize their welfare in a market economy. Trade therefore introduces a cooperative solution.

2.5 Cooperative market exchange vs autarky

In the first stage of the game, finally, the two groups have to choose what regime they prefer to be in; autarky or a market economy. By the backward induction logic, we therefore now insert the solutions for x_i^*, p^*, and R_i^* and compare indirect utilities. The market outcome will be chosen whenever what we refer to as the 'market equilibrium condition' applies:

$$V_f^m \geq V_f^a \ \vee \ V_h^m \geq V_h^a \tag{15}$$

In all other situations, autarky will prevail. Hence, only if both groups are willing to engage in trade will there be a market regime. We will assume that this market equilibrium condition is the status quo situation and analyze under what conditions this choice of regime might break down.

For farmers, the relevant comparison is

$$\frac{V_f^m}{V_f^a} = \sqrt{\frac{L_h^{1-\alpha_f}}{L_f^{1-\beta_f}} \frac{R^{\alpha_f - \beta_f}}{\pi^{\alpha_f + \beta_f}} \eta} \tag{16}$$

where we have substituted in $R_f^{m,*} = R_h^{m,*} = R/2$ and $R_f^{a,*} = \pi R$ and where $\eta = 1/\chi 4^{1+\alpha_f}$. Analogously, the relevant comparison for herders is

$$\frac{V_h^m}{V_h^a} = \sqrt{\frac{L_f^{1-\alpha_f}}{L_h^{1-\beta_f}} \frac{R^{\beta_h - \alpha_h}}{(1-\pi)^{\alpha_h + \beta_h}} \eta}. \tag{17}$$

The results in (16) and (17) allow us to state the following key result:

Proposition 1: *The likelihood of a cooperative market solution increases with the level of the common resource R, with the size of comparative advantages $\alpha_f - \beta_f$ and $\beta_h - \alpha_h$, and with a relatively equal distribution of bargaining powers and population sizes so that $\pi = 1/2$ and $L_f = L_h$.*

Proof: Straightforward comparative statics shows that $\frac{\partial\left(V_f^m/V_f^a\right)}{\partial R} = \frac{\left(\alpha_f - \beta_f\right) V_f^m}{2RV_f^a} > 0$ and $\frac{\partial\left(V_h^m/V_h^a\right)}{\partial R} = \frac{(\beta_h - \alpha_h) V_h^m}{2RV_h^a} > 0$ since $\alpha_f - \beta_f = \beta_h - \alpha_h > 0$. The results regarding π, L_f and L_h follow from the fact that the outcome of the choice of a market regime will be determined (from (15)) by whether or not $\min\left(V_f^m/V_f^a, V_h^m/V_h^a\right) > 1$. This minimum level is maximized when $\pi = 1/2$ and $L_f = L_h$.

The key result from the proposition above is that a greater level of effective natural resources R increases the probability of a cooperative market solution and that the positive impact of R will increase with the elasticity differences (or magnitude of comparative advantages) $\alpha_f - \beta_f = \beta_h - \alpha_h$. This implication differentiates our approach from the spirit of several theoretical contributions on the curse of natural resources where a greater resource abundance often leads to unproductive rent seeking and a less well functioning economy.[7] The intuition behind our result is essentially derived from the fact that for the economy as a whole, the total output elasticity and productivity of land is greater in the specialized market economy. All land is then used for the production of the good which farmers and herders have a comparative advantage in producing. Hence, a high (low) level of R will give this factor of production a great (low) weight in the production and indirect utility functions and make a market choice more likely (less likely).

The results regarding the distribution of bargaining power π and population sizes are also fairly easy to grasp. Should farmers' political and bargaining power π be very large, maybe even close to unity, then their interest in a cooperative division of the resource is relatively small since they can obtain a lot more of R by not cooperating. Equivalently, if L_f is substantially greater than L_h, then the relative price of meat from the herding community will be very high, which will decrease farmers' willingness to participate in a market economy. If both bargaining power and population levels are evenly distributed, there will neither be a large redistribution of land, nor a price shock to one of the groups in the case of a market economy, which makes such a regime more likely.

3 Appropriative conflict

In the section above, representative individuals in the two groups could choose between on the one hand a cooperative market solution, and on the other hand a noncooperative solution without trade where political and bargaining power determined the allocation of the common resource. There was, however, no appropriative conflict on a scale that actually required individual resources. The Nash bargaining process was carried out without worker effort and people always accepted the outcome. In this section, we introduce two new aspects to the model: Firstly, a Malthusian subsistence level of consumption below which some group members are forced to leave the community, and secondly, the possibility that these excluded people start to prey on the resources of the other group in the region.

Starting with the first aspect, it has been common since Malthus (1798) to assume that below a certain level of food consumption, population growth

[7] See for instance Collier and Hoeffler (2004), Mehlum et al (2006), Olsson and Congdon Fors (2004), and Olsson (2007).

will decline and even turn negative. There could be several specific mechanisms that generate this effect, for instance death from famine, reduced fertility, migration, or violent conflicts. We will assume the following scenario: If per capita consumption in a group descends below a certain threshold subsistence level, a social mechanism sets in that induces a sufficient number of people to leave the group so that the subsistence equilibrium level is sustained. What we have in mind is an 'insider-outsider'-like setting where certain people are more deeply embedded in society than others and that those who are least embedded or integrated in the group and who have the weakest claims on land, will be those that have to leave first. This latter category of people typically includes migrants, members of other ethnic groups, landless and unmarried young men, widows, disabled or sick people, criminals and outcasts.[8]

The second key assumption that we make is that this excluded category of people will have as their only survival strategy to try to conquer land from the other group in the region through appropriative conflict. In this sense, we now turn to a variant of predator-prey models and conflict theory in the spirit of Hirshleifer (1995) and Grossman and Kim (1995).

Let us assume that we now have an autarkic, non-cooperative situation where the land distribution is $R_f = \pi R$ and $R_h = (1 - \pi) R$ and where there is no trade. Let us also assume, for the sake of simplicity, that we can express the total output (consisting of both self-produced meat and crops) for representative individuals in the two groups, Q_f and Q_h, by a single aggregate production function

$$Q_f(R_f) = (R_f/L_f)^{\alpha} x_f^{\gamma}; \quad Q_h(R_h) = (R_h/L_h)^{\beta} x_h^{\delta} \tag{18}$$

where R_i/L_i is land per capita as before and where $x_i \leq 1$ is the time allocated to productive activities out of a total time endowment equal to one. Neither group can observe the production of the other group. In the initial peaceful scenario, we will have that $x_f = x_h = 1$. We make the standard assumption in the literature of constant returns to scale so that $\alpha + \gamma = \beta + \delta = 1$.

We will next describe utility. Since the economy is autarkic and since

[8] See for instance André and Platteau (1998) on the strained rural situation in Rwanda leading up to the 1994 genocide, or Prunier (2007) for a description of the long build-up to the crisis in Darfur.

saving is not possible, total own production equals total own consumption. The utility of the two representative agents are therefore independent of each other in the standard peaceful scenario and linear in consumption/production:

$$U_i = Q_i\left(R_i\right) \quad \text{where } Q_i \geq \bar{Q} \quad \text{for } i = f, h \tag{19}$$

There is now, however, a threshold subsistence level of consumption $\bar{Q}$ below which people will start starving. Survival is possible in the short run but not on a longer term basis. As we shall see, both communities have an exclusion mechanism that sees to that the subsistence level is not passed for the representative individual.

The model features the following sequence of events: 1) Both groups' representative individuals foresee their levels of consumption, taking as given observed levels of population and resources. 2) If predicted consumption levels are above the long-run subsistence level, peaceful production ensues among both groups. If predicted consumption levels are below long-run subsistence for one of the groups, this group will ostracize its least integrated members so that the subsistence level is restored among remaining members. The starving outcast members then attack the other group in order to capture land. 3) Members of the attacked group allocate time both to defending themselves and to producing. 4) The two main groups consume their production whereas the outcasts survive in the short run on the conquered resources. For simplicity, we will assume throughout the analysis that the most vulnerable group is the herder group.

The first event is that both groups predict their own levels of consumption (without observing the other groups' production). The herding community is assumed to be the most vulnerable group, and the critical issue for them is whether they will be above or below subsistence consumption $\bar{Q}$. By setting (18) equal to $\bar{Q}$ and $x_h = 1$, we can derive the critical level of population, $\bar{L}_h$:

$$\bar{L}_h = \frac{R_h}{\bar{Q}^{1/\beta}} = \frac{(1-\pi)\,R}{\bar{Q}^{1/\beta}}.$$

In periods of extreme Malthusian stress, it might be the case that total herding population exceeds this level, in which case we assume that those who are at the bottom end of the social hierarchy are socially excluded. The size of this excluded category in the herding community is defined by

$$N_h = L_h - \frac{(1-\pi)R}{\bar{Q}^{1/\beta}} \geq 0 \tag{20}$$

The normal situation is of course that $\bar{L}_i > L_i$ so that $N_i = 0$. The expressions above indicate that the level of N_h (or the probability that N_h exceeds zero) increases with the total size of the population in the community L_h, and decreases with the share of herder land held $(1-\pi)$, and with the total effective stock of land R. If emigration from the region is not an available option, perhaps due to geographical or political barriers, it is clear that N_h will typically constitute a socially destabilizing factor. Since these people are desperate, they are the perfect material for political, ethnic, or religious manipulations. We assume that the only survival option open to the excluded people in N_h is to engage in a one-shot appropriative struggle aimed at capturing land from the other community.

If $N_h > 0$, this outcast group of herders will attack farmer territory in the second stage whereupon farmers will rationally defend themselves. More specifically, each farmer might devote a part of his or her time $d_f = 1 - x_f$ to defensive effort. Total defensive effort is thus $d_f L_f$. As we shall see, d_f will only be positive if N_h is positive.

In line with much of the literature, we assume that the outcome of the appropriative struggle can be illustrated by a typical contest success function

$$\rho(d_f, N_h) = \frac{d_f L_f}{d_f L_f + \theta N_h} = \frac{1}{1 + \frac{\theta N_h}{d_f L_f}} \tag{21}$$

where ρ is the share of farmer land that farmers manage to save from the invading outcast herders, and where θ reflects herder's relative military strength.[9] $\theta < 1$ implies that farmers are relatively stronger than the herders, and vice versa. The function above has the standard features that $\partial\rho(\cdot)/\partial d_f > 0$, $\partial^2\rho(\cdot)/\partial d_f^2 < 0$, and that $\partial\rho(\cdot)/\partial N_h < 0$.

The post-conflict sizes of land-holdings for the two fighting groups are

$$\tilde{R}_f = \rho(1-\omega)\pi R; \quad \tilde{R}_{oh} = (1-\rho)(1-\omega)\pi R; \tag{22}$$

where $\tilde{R}_{oh}$ is the land conquered by the outcast herders. In this expression,

[9] See for instance Grossman and Kim (1995) or Olsson (2007) for a similar assumption.

we introduce the new term $\omega \in (0,1]$ which captures the destructiveness of the conflict on πR. If a conflict arises, a fraction ω of total farmer land πR is lost to both sides. The land of the non-fighting herders, $(1-\pi)\,R$, is not affected.

At the third stage, farmers thus face a trade-off between allocating time to producing on their land and defending their land. After substitutions, the maximization problem becomes:

$$\max_{d_f} U_f = \max_{d_f} \left(\frac{(1-\omega)\,\pi R}{L_f + \frac{\theta N_h}{d_f}} \right)^{\alpha} (1-d_f)^{\gamma} \tag{23}$$

By taking first-order conditions, we can derive the representative farmer's best response function:

$$d_f^* = \frac{\theta N_h\,(\alpha+\gamma)}{2\gamma L_f} \left(\sqrt{\frac{4\alpha\gamma L_f}{\theta N_h\,(\alpha+\gamma)^2} + 1} - 1 \right) \tag{24}$$

This somewhat complicated function turns out to have fairly straightforward implications. Most importantly, d_f^r is a positive, concave function of effective herder offensive strength θN_h. In other words, defense efforts will increase with increases either in relative strength θ or in the number of herder outcasts N_h. Figure 1 shows how the best response-function varies at different levels of L_f, α, and γ. For example, if the ratio of farmer population to effective herder attacking strength is $L_f/\theta N_h = 5$ and if $\alpha = \gamma = 1/2$ (the upper line in the figure), the representative farmer will spend roughly 29 percent of his/her time on defense efforts ($d_f^r = 0.289\,90$). Note also that $d_f^r\,(N_h = 0) = 0$.

By using (20) and (24), the total scale of the appropriative conflict, measured in terms of the total amount of labor resources spent on attacking and defending, can be summarized in a single expression

$$d_f^* L_f + N_h = \Lambda\left(\theta, L_f, N_h\left(L_h, \pi, R\right)\right) \tag{25}$$

which, in turn, forms the basis for Proposition 2:

Proposition 2: *The scale of appropriative conflict increases with the attacking group's military strength θ, with population sizes L_f and L_h, and with the defending group's proportion of land π, and decreases* *with land resources R.*

Proof: See the Appendix.

Once again, a key insight in this expression concerns the level of resources R. In the scenario above, a decrease in R - perhaps due to climate change - pushes some herders over the subsistence threshold and forces them to prey on the farmers. Farmers will in turn have to devote labor effort to defending themselves. In this way, a deterioration in R might cause an appropriative conflict to arise and its intensity to increase. This is the opposite effect of for instance the mechanism in Olsson and Congdon Fors (2004) and many other works on natural resources and rent seeking. This difference in results of course stems from the different assumption regarding the representative agents' utility function in (19) where predation is not an option except at below subsistence consumption.

Once a conflict has started, the relative military strength of herders θ has a positive effect on overall conflict intensity since the defending group will need to exert more effort to defend themselves. Further, if more land had been allocated to herders in the first place, i.e. if π had been lower, both conflict risk and conflict intensity would have been smaller.

From (22), we can infer that in the end, the appropriative conflict against the herders causes farmers to lose a proportion of their land equal to

$$\frac{\pi R - \tilde{R}_f}{\pi R} = 1 - \rho^* + \rho^* \omega$$

where $\rho^* = \rho\left(d_f^*, N_h\right)$ is the equilibrium share of land left to farmers. Apart from the loss to the fighting herders $(1 - \rho^*)$, there is also a pure waste component $\rho^* \omega$ which obviously increases with the destructiveness of the struggle ω.[10]

4 Long-run resource and population dynamics

In all the settings above, both the population levels and the level of basic natural resources were assumed to be exogenous. In this last theoretical

[10] In a more elaborate model, one might imagine relaxing the assumption concerning the agents' information about each others' production and willingness to fight. In such a scenario, farmers might foresee the loss from a struggle with the herders and might be willing to concede land ex ante in order to avoid a costly fight.

section, we will now endogenize resources and population levels in the spirit of Brander and Taylor (1998) and their followers.[11] Resources are assumed to evolve according to a standard logistic function for renewable resources, whereas population growth responds positively to levels of resources per capita in a Malthusian manner. We thereby move to a long-run dynamic setting where aspects like climate change can be explored in a more interesting way.

Unlike before, we will now consider the macro level, i.e. the development of the economy as a whole, and assume that over the long run we should be able to characterize total production by the two groups as a composite process.

The renewable natural resource land has the following equation of motion:

$$\dot{R}_t = R_t \left(r \left(1 - \frac{R_t}{K} \right) - \lambda L_t \right) \tag{26}$$

In this expression, $r > 0$ is the "intrinsic" growth or regeneration rate of the natural resource, $K > 0$ is the carrying capacity of the land (or the upper boundary of R_t), and $\lambda > 0$ is the extent to which the total population uses up the existing resource stock.[12]

Population growth in the region as a whole is assumed to be

$$\dot{L}_t = L_t \left(g + \frac{\phi R_t}{L_t} \right) \tag{27}$$

where $g < 0$ is the negative intrinsic population growth rate and where $\phi > 0$ measures the sensitivity of population growth to resources per capita. ϕ might thus be described as measuring the strength of the Malthusian link between population and production. When resources per capita are high, population growth is relatively high, and vice versa. Since $g < 0$, there will exist a subsistence level, similar to that above, below which $\dot{L}_t < 0$. The exact mechanism through which this population decline comes about will now be left open but could result through a collapse of cooperative markets

[11] See for instance Pezzey and Anderies (2003) and Maxwell and Reuveny (2000, 2005). An alternative paradigm, arguing that population increases gives rise to technological change, is famously described by Boserup (1965).

[12] Numerous other works have previously used variants of this resource stock equation, including Brander and Taylor (1998). In this model's setting, the negative part on the right-hand side is not a standard "harvest function", as in most models, but is meant to reflect that higher population levels imply an increased depletion of the resource stock through both higher production and negative externalities from production.

or because of lethal conflict, as in the previous sections, or even through migration or starvation.

By setting (26) and (27) equal to zero, we can plot the two equations in a phase diagram as in Figure 2a. We can also solve for the steady-state equilibrium levels of resources and population which turn out to be:

$$R^* = \frac{grK}{gr - \phi\lambda K} > 0 \quad (28)$$

$$L^* = \frac{\phi rK}{\phi\lambda K - gr} > 0 \quad (29)$$

The central insights regarding the steady-state levels can be summarized as in the proposition below:

Proposition 3: *a) The steady-state level of land resources R^* increases with carrying capacity K and with the natural regeneration rate r, and decreases with the strength of the Malthusian link ϕ and with the intrinsic population growth rate g. b) The steady-state population level L^* increases with carrying capacity K, with the regeneration rate r, with the strength of the Malthusian link ϕ, and with the population growth rate g.*

Proof: See the Appendix

Climate change is most easily thought of here as changes in carrying capacity K. The vulnerable environments that we have in mind typically experience an ongoing deterioration in climate with decreasing precipitation and an increasing desertification. Such changes causes K to fall, which in our model implies that the steady-state levels of resources and population will both fall. It is also noteworthy that the steady-state level of resources will decrease with the strength of the Malthusian link, ϕ. Should ϕ fall, perhaps due to policy-induced changes in fertility behavior, this would result in a diminished pressure on natural resources.

The transitional dynamics of the system above also has interesting features. In Figure 2b, we illustrate the simultaneous effect of two types of changes; a short-run resource per capita shock and a long-run deterioration in carrying capacity. The resource per capita shock could perhaps be due to a random natural disaster that leads to a temporary fall in R_t, accompanied by an inflow of people from an even more affected region. Both types of shocks will cause a serious stress on the community, and resources per capita will fall from the initial steady-state equilibrium E to the point E', which is clearly not an equilibrium. The immediate implication will be that Malthusian forces set in so that population levels start to fall, whereas the too high levels of population also causes land deterioration.

A drawn-out process of population decline will then set in, whereas resources slowly start increasing again. The population decline will continue even beyond the new steady-state level $L^{*,new}$, and in this interval of relatively empty lands, resources will catch up quickly. Population levels will then once again start to recover, which causes total level of resources to fall back somewhat, until the system comes to rest at the new steady-state at $R^{*,new}, L^{*,new}$.[13] As implied by the comparative statics in the proposition, both resources and population are now at a lower level.

5 An application to Darfur

In this section, we will briefly relate the predictions from the models above to one particular current conflict episode; Darfur. There are at least three reasons for this choice of study object: Firstly, Darfur lies in the African Sahel region, which has been identified as one of the most vulnerable environments in the world in the years to come (Stern, 2006; IPCC, 2007). Secondly, several studies have indicated that conflict over scarce land has been a key factor in Darfur (UNEP, 2007). Thirdly, and most importantly, Darfur is arguably the most serious humanitarian disaster in the world at present with about 300,000 dead since 2003 and with more than 2 million internal refugees (Reeves, 2008).

5.1 Context[14]

Darfur is located in western Sudan, bordering Chad, Central African Republic, and Libya. The heart of the region is the Jebel Marra massif which peaks at 3000 meters and its slopes have a quite different climate and vegetation from the surrounding Sahelian plain. The region is divided into

[13] See Brander and Taylor (1998) for an analysis of how ongoing cycles in population and resource levels appear to have been a characteristic feature of several historical societies.

[14] The general information presented in this section builds upon Flint and De Waal (2008), Prunier (2007), and UNEP (2007).

three administrative states; Northern, Western, and Southern (see Figure 3) which together add to about 500,000 km^2(roughly the size of Spain). Darfur is geographically distant from the core region of Sudan, which is located around the capital Khartoum where the Blue and the White Nile Rivers meet. It is further on the eastern edge of the Sahel cultural zone and is one of the most landlocked areas in the world. This geographical peripherality of Darfur is also reflected in a sense of political marginalization within the Sudanese state, as will be discussed below.

It is estimated that Darfur harbours around 6-6.5 million people and that the population has increased by 3 million since 1983 (D-JAM, 2006). The population consists of a multitude of ethnic groups, each with their more or less recognized traditional homeland ("Dar"). Land ownership within homelands is primarily communal and the main livelihood strategies are subsistence agriculture and pastoralism.

One of the largest and traditionally most dominant tribes is the Fur who occupy the slopes of Jebel Marra where they cultivate sorghum and millet.[15] Another important farming tribe in Western Darfur is the Masaalit, whereas the northwestern parts are home to the Zaghawa, a camel and sheep-tending pastoralist tribe. These three tribes are usually referred to as "African" and have played key roles in the Darfur conflict. The "Arab" tribes are often discussed under the common heading of Baggara but actually includes several distinct tribes such as the Rizeigat, with their homeland in southern Darfur. It should be emphasized that intermarriage and a general mixing of populations makes the African-Arab distinction arbitrary, at least in peace-time. The Baggara are mainly cattle herders, some nomadic, others sedentary. An important fact is further that all tribes of Darfur are Muslim.

5.2 The Darfur conflict

In this section, we give a brief overview of critical events in the Darfur conflict until present time.[16] In the literature, three main conflict dimensions have been identified (Brosché, 2008): 1) A *core-periphery conflict* between marginalized Darfurians (and some former government elements) on the one side and the government in Khartoum on the other. 2) A *proxy war between*

[15] The same "Darfur" simply means "the home of the Fur".

[16] General sources for this section have been Flint and De Waal (2008), Brosché (2008), Prunier (2007), UNEP (2007), and United Nations (2005).

the governments of Sudan and Chad. 3) *A local resource conflict*, based on competition over diminishing natural resources, between mainly African farmers and Arab pastoralists.

We will discuss each aspect in turn, starting with the core-periphery dimension. For centuries, Darfur was an autonomous sultanate dominated by the Fur that had its center in the Jebel Marra area. When central Sudan came under British control after the battle of Omdurman in 1898, Darfur retained a certain degree of independence. This era eventually ended in 1916 when the British incorporated the area into the greater colony. Sudan achieved full independence in 1956. It is generally recognized that the colonial period, as well as the independence era from 1956, both meant an increasing marginalization of Darfur, a fact which all rebel groups claim to be an important factor behind their resistance today. The central government's long war against the SPLA rebels in the southern provinces also contributed to the marginalization.

Events in the political center of Sudan also contributed to the Darfuri conflict. In 1989, the Colonel Omar al-Bashir and the National Islamic Front (NIF) staged a successful coup and assumed power in Khartoum. A key supporter of the coup was the Islamist ideologue and political leader Hassan al-Turabi, an internationally reputed Muslim scholar. In 2001, al-Turabi had a falling-out with President al-Bashir and then responded by promoting a new Islamic movement aimed at gaining support from Sudan's more marginalized areas. One of the Darfuri rebel groups, JEM, picked up al-Turabi's agenda and has since been repeatedly accused of having links with JEM.

Many sources point to the key importance of the big Sahelian famine in 1984-85 (which also famously affected Ethiopia) for understanding the Darfurians' sense of marginalization. Despite early signs of a coming disaster, the government in Khartoum declined to organize any effective help to Darfur. By August, some 80,000 environmental refugees fled the drought-affected areas and set up camp outside Khartoum. By springtime 1985, the famine was estimated to have taken around 95,000 lives (Prunier, 2007).

It is further impossible to understand the Darfuri conflict without discussing the role played by Sudan-Chad relations. During the 1980s, the government in Chad was under increasing pressure from rebel groups supported by Libya. The rebels, led by the Zaghawa tribesman Idryss Déby, as well as regular troops from Libya, had bases in Darfur from where they launched attacks on Chad. Libya's Colonel Ghadaffi also armed Arab militias among the Darfurian tribes. These militias then frequently raided African tribes such as the Fur, sometimes even with the support from the government in Khartoum. In late 1990, Idryss Deby and his fellow Zaghawa finally were victorious in the long civil war and ousted the incumbent government in N'Djamena.

With the onset of the Darfuri conflict, tensions between the Chadian and the Sudanese governments have further increased. In February 2008, Chadian rebels based in Darfur - and by some believed to be supported by Khartoum - crossed several hundred kilometers of ground and launched an attack on the capital N'Djamena, which seriously threatened the Chadian regime. Only after French military intervention, the rebels were finally forced to retreat. In May, finally, the Zaghawa-dominated rebel group JEM, also based in Darfur, carried out a surprise attack on Omdurman in the heartland area of the government. No other rebel group in Sudan had previously been that close to Khartoum. The Sudanese government immediately accused Chad of supporting JEM. The broader significance of this dramatic incident still remains to be seen.

The third dimension, emphasizing local resource conflict, is inescapably intertwined with the other two dimensions. The big drought and famine in 1984-85 brought a serious disturbance to the fragile ecological balance between the pastoralist tribes and the farming communities. The pastoralist tribes typically moved from northern to southern Darfur with their herds over farming lands during February-March and then returned during May (see Figure 4). The drought forced farmers to intensify their cultivation and attempts were made to seal off land from the pastoralists. Somewhat paradoxically, during the unusually dry period in the mid 1980s, the central parts of Darfur still received a large number of immigrants from even drier regions in the Sahel belt. These were mainly nomadic pastoralists from Chad, often kinsmen to existing groups in Darfur, who were attracted by the richer pasture on the Jebel Marra slopes (Flint and De Waal, 2008). Deadly clashes between for instance Fur farmers and Rizeigat herders were common during this period, as well as during recurring droughts in the late 80s and early 90s, killing thousands and making tens of thousands homeless

(United Nations, 2004).[17] We will focus on the resource conflict in the sections below.

The major conflict in Darfur is usually considered to have started in February 2003 with the launch of Justice and Equality Movement (JEM) and the Sudan Liberation Movement (SLM) and their attacks on government outposts. Both groups had national agendas aimed at installing a new government that cared about all regions of Sudan. It is likely that both groups considered the approaching peace and power sharing deal with the southern regions as a step towards an even further marginalization of Darfur. The SLM had the Fur and the Masaalit tribes as their basic sources of recruitment whereas JEM was based on Zaghawa and had a more pronounced Islamic programme.

For a few months, the rebels could roam free in Darfur without meeting much government resistance.[18] This was to a great extent explained by the fact that most of the regular government army was stationed in the South, fighting the SPLA. The lack of military capacity in Darfur, as well as the seriousness of the threat, then led the government to mobilize the Arab militias that had been active in the area from time to time since the 1980s. The government provided aircraft and intelligence whereas the militias were hired to do the work on the ground. These "Janjaweed" fighters[19] - mounted on horses, camels or pickups - would typically beat up or shoot the surviving men, loot the buildings, rape women and girls, steal or destroy all means of production, and finally set the whole village ablaze (Prunier, 2007). From this strategy then followed a conflict pattern that was repeated numerous times during the particularly intensive periods June-September 2003 and the early months of 2004, involving massive attacks on civilian targets in rebel-dominated areas (Petersen and Tullin, 2006a).

By April, 2008, the UN head of humanitarian affairs estimated that about 300,000 people had been killed since 2003 (BBC, 2008). 2,45 million people (out of a total population of maybe 6 million) are currently internally displaced, finding shelter in camps within Darfur, while some 250,000

[17] Two of the most serious conflicts were the so-called Arab-Fur war in 1987-89 and the Arab-Masaalit conflict 1995-99 (Flint and De Waal, 2008).

[18] The most spectacular rebel attack was probably the destruction of a number of Antonov planes and combat helicopters at the El Fasher airport on 25 April, 2003 (Flint and De Waal, 2008).

[19] The term "Janjaweed" is a local Arab word for "evil horsemen".

Darfuris are refugees in Eastern Chad (Reeves, 2008). The majority of the population - more than 4 million people - are directly affected by the conflict.

5.3 Resources and population

The key variable in all three models outlined above is natural resources R. In Darfur, the relevant natural resource is land. As in most parts of Sudan, the land is typically arid or semi-arid and the relatively most fertile areas are found on the Jebel Marra plateau.

Whereas the total size of the land is more or less constant, precipitation varies from year to year and is the major factor determining land productivity over time.[20] Rainfall data is further measured with a certain accuracy and has previously been shown to have an influence on economic growth rates and conflict risk (Miguel, 2004). Figure 5 shows the deviation from the long-term mean in precipitation for Africa during 1990-97. The picture is very similar for the 1970-79 and the 1980-89 eras. The noteworthy feature is the dramatic decline in rainfall, often by more than 20 percent, in the Sahel region and in parts of Southern Africa, whereas East Africa has had above average rainfall. An unusually dry period in the Sahel appears to have started around 1970. Although many would argue that these changes are due to greenhouse warming, it is noteworthy that a similarly dry period happened in the first half of the 19th century (Nicholson, 2001).

The long-run pattern of precipitation in Darfur is summarized in an extremely condensed form in Figure 6. It shows that in all the three Darfur states, the average annual rainfall has declined during the last thirty years as compared to the 1946-75 period. This data, provided by UNEP (2007), has formed the basis of most recent discussions of the role of climate change in the Darfuri conflict.[21] Using more detailed data, Kevane and Gray (2007) confirm that there indeed appears to have been a structural break in precipitation around 1972 whereafter rainfall appears to have decreased by

[20] Other natural processes such as desertification, erosion, salinization, and deforestation also affect the overall quality of land, but we will refrain from analyzing such factors here.

[21] See for instance Sachs (2006) and Ki Moon (2007). The UNEP report (2007, p 60) describes the situation as follows: "The scale of historical climate change as recorded in Northern Darfur is almost unprecedented: the reduction in rainfall has turned millions of hectares of already marginal semi-desert grazing land into desert. The impact of climate change is considered to be directly related to the conflict in the region, as desertification has added significantly to the stress on the livelihoods on pastoralist societies, forcing them to move south to find pasture."

about 20 percent. Their data further reveals that there were major drought episodes in 1975-77, 1984-85, around 1990, and again around the year 2000.

Population is another factor that plays a key role in our model. Figure 7 shows the population trend from 1956 to 2003, based on official data from D-JAM (2006). Noteworthy features are that population has increased by a factor of nearly 5 between 1973 and 2003 (from 1.34 million to 6.48 million) and that there appears to have been a structural break in population growth around 1973. This is particularly remarkable since the same period has had a marked decline in rainfall. If we assume that land productivity has decreased on average by 20 percent due to rain failure, effective resources per capita in 2003 should only be about one sixth of the level in 1973.[22] This must be regarded as a quite remarkable deterioration.

Why was there an increase in population growth rates in the early 1970s despite a downturn in the rainfall trend and a major drought around 1976? This paradox seems most likely to be explained by an inflow of pastoralist populations from neighbouring regions of the Sahel that experienced an even greater hardship due to the changing conditions.[23] There simply appears to have been no better place to go.

5.4 Conflict analysis

As the review above has shown, the conflict in Darfur has several different dimensions. In the section below, we will focus on the resource conflict-dimension. Obviously, modelling all dimensions of the conflict in Darfur is not viable. Given the current situation for data collection, it is further impossible to carry out rigorous econometric tests on the basis of our hypotheses. Instead, we will have to resort to using information from various sources and make an informal analysis of how the available data fit the implications from the models developed above.

[22] More specifically, let us normalize effective resources (land) per capita in 1973 to be 1/1=1. Whereas effective land depreciated by a factor 1,2 due to drought, total population increased by a factor of 4,836. Hence, effective resources per capita in 2003 are (1/1,2)/(1*4,836)=0,172, i.e. slightly more than $\frac{1}{6}$ of the level in 1973.

[23] In Flint and De Waal's (2008, p 43) words: "Recurring drought in Chad gave additional impetus to immigration into Darfur.//In the 1980s, not just Abbala Rizeigat but whole clans of Beni Halba, Missiriya and Mahadi moved eastwards to join their kinsmen in a swathe or territory reaching from the border at Geneina as far as Kebkabiya and Kutum. Further south, the Salamat nomads - cattle-herders - were drifting eastwards too, seeking land and security."

Our model assumed two main groups, *farmers* and *herders*, with different livelihood strategies and comparative advantages and who competed for the same basic land resource. This basic setting applies well to Darfur where the majority of the population are either subsistence farmers or pastoralists, organized in geographically bounded homelands ("dars") within which land is primarily communal. However, it should be noted that although the SLA rebels mainly are farmers, the JEM are mainly made up by the pastoralist Zaghawa, which complicates the picture to a some extent.

We will now compare the basic features of the model with actual facts from Darfur, starting with the market integration model:

Implications from market integration model: *The likelihood of a cooperative market solution increases with the level of resources* R *and with an equal distribution of population sizes* L_f *and* L_h *and of bargaining power* π*.*

There are many indications that a kind of market integration actually broke down after the 1970s, following the decline in effective resources. More specifically, many sources identify the great famine in the mid 1980s as a critical turning point in relations between pastoralists and farmers in Darfur:

> "The groups confronting each other in the current conflicts have a long history of guarded cooperation and relative peaceful co-existence. In the past, they exchanged goods and services; indeed some of the herds that the Arab nomads reared belonged to wealthy Fur who did not opt to become nomads themselves. The Fur sold most of their herds on the onset of the drought in 1983/83. This was considered a severance of economic relations, which strained the relations between the Fur and the Arab." (UNICEF, 2003, p 53)

Flint and De Waal (2008, p 45) in turn describe the wider impact for the Darfurians of the 1984-85 famine:

> "...survival came at a price which was only apparent later: they exhausted their land, their assets, and their hospitality. The fabric of rural life never fully recovered."

As already documented above, there was further a very uneven inflow of people into Darfur during these decades. Nomadic pastoralist peoples from Darfur and neighbouring Chad were clearly the main immigrant group, causing the L_f/L_h-ratio to fall. This in turn should have implied that the relative price of traded agricultural goods increased, which decreased the herders interest in trading. Furthermore, there are strong indications of that the "Arabization"-strategies of the national government - which included supporting local Arab militias since the 1980s against "African" tribes - had changed the non-cooperative bargaining power in favor of the pastoralist Arabs (United Nations, 2005; Prunier, 2007), causing a lower π. Both these developments would, according to our model, imply that mainly herders opted out of the the cooperative solution and that market integration thereby collapsed.

Implications from the appropriative conflict model: *The scale of appropriate conflict increases with the attacking group's military strength θ, with population sizes L_f and L_h, and decreases with land resources R. The attacking individuals should be among the least integrated in their home community.*

In the appropriative conflict scenario, we propose as our main scenario that pastoralist groups in Darfur constitute the attacking group (the Janjaweed) which predate on the farmers. Indeed, in a survey of 178 attacks throughout Darfur, Petersen and Tullin (2006a) found that 97 percent of all attacks were carried out by the Janjaweed or the government. This basic scenario still needs a number of qualifications. Firstly, it is well known that farming tribes such as the Fur have often attacked nomadic groups. Second, the great majority of herders in the region have nothing to do with the Janjaweed (which indeed is also suggested by our model). Thirdly, not all rebels are farmers (the Zaghawa). Fourthly, it was actually the rebel groups that formally started the recent war by attacking the government, which is not a player in our model. Nonetheless, we think the basic characterization of predator and prey as posed in this part is fair on the whole.

A major difference between the conflict that started in 2003 and those in earlier years is undoubtedly the relative military strength of the predators, θ. Numerous witnesses have testified that the Janjaweed militia were generally supported by government aircraft and intelligence in their attacks, which is likely to have made the relatively few Arab militiamen remarkably effective. This should in turn have increased defensive efforts and the scale of the conflict in general. One of many similar witness accounts, collected by Petersen and Tullin (2006b), remembers the attack on Kerana in August, 2003:

> "The village was attacked at 6am by men on horses, camels, three Antonov airplanes, two MIGs and in the cars. The Janjaweed arrived first on horses, then the government forces and then the planes. Some 150 people were killed, 3 women, 4 children and the rest men. The Janjaweed took away 300 cows, 400 goats and 200 camels, as well as money."

It is likely that the fast increase in total population $L_f + L_h$,shown in Figure 7, should also have contributed to the greater scale of the conflict.

The model further features that a decline below some Malthusian threshold level of income $\bar{Q}$forces people on the margin of pastoralist societies to take up arms. Many sources appear to support this prediction about the clientele of the fighting groups. Prunier (2007, p 97) writes:

> "Sociologically, the Janjaweed seem to have been of six main origins: former bandits and highwaymen who had been "in the trade" since the 1980s; demobilized soldiers from the regular army; young members of Arab tribes having a running land conflict with a neighbouring "African" group - most appeared to be members of smaller Arab tribes; common criminals who were pardoned and released from gaol if they joined the militia; fanatical members of the Tajammu al-Arabi; and young unemployed Arab men, quite similar to those who joined the rebels on the "African" side."

Implications from the long-run resource and population model: *Climate change that decreases long-run carrying capacity K should result in a period of transition to a new equilibrium with lower levels of resources and population. A negative shock in resources per capita might lead to a drawn-out transition process where the population level shrinks below even its long-run equilibrium.*

It seems beyond doubt that climate has actually become much drier in Darfur since the 1970s. This has in turn decreased carrying capacity, which means a new long-run equilibrium. From a Malthusian perspective, one might thus view the last decades of conflict with hundreds of thousands people dead as an adaptation to this new situation. One might also think of the serious droughts such as the one in 1984-85 as a shock that pushed the economy to a point such as E'in Figure 2b. This adaptation appears to be going on even now, since fighting has not ceased.

What the model also predicts, however, is that eventually, the killing will cease, and those that have survived will then move to relatively sparsely populated lands, which actually have recovered very well due to the temporarily lower population pressure. After some population undershooting and some resource overshooting, the system should settle at last at the new equilibrium.[24]

6 Conclusions

In this paper, we have developed three models or scenarios of resource conflict in vulnerable environments - the market integration model, the appropriative conflict model, and the long-run resources and population model. Each model offers a different angle of resource conflict and describes a gradually intensifying resource conflict that starts with a collapse of the market economy and ends with a long-run adaptation of population and resources to a new (Malthusian) equilibrium. The major engine of change in the model is a fall in effective basic natural resources per capita.

In the empirical section, our calculations suggest that effective land resources per capita in Darfur have declined by about 5/6 since 1973 due to climate deterioration and population increases. This should have contributed to the observed market disintegration, to the outbreaks of appropriative conflicts, and to the ongoing transition to a lower equilibrium. Factors under government control, such as herder bargaining power and the relative military strength of the Arab militias, have probably also contributed to the intensity of fighting.

Needless to say, the analysis above does not satisfactorily either corroborate or refute the hypotheses developed in the models. The nature of the data simply does not allow more rigorous testing at the moment.

[24] There are clear analogies to Rwanda here: Despite 800,000 people were butchered in 1994, the ethnic groups in the country have since then lived in relative peace. See André and Platteau (1998) for an analysis of Rwanda.

Many important aspects are not considered at all by the models; the role of the government as a player, the core-periphery dimension, the foreign involvement, etc. Hopefully, future work on Sudan and on other vulnerable environments might shed more light on these issues. We believe that our theoretical framework might be a useful point of departure in this endeavour.

7 Appendix

7.1 Proof of Proposition 2:

From (20) and (24), we can write total labor effort devoted to appropriative conflict as

$$\begin{aligned} d_f L_f + N_h &= \\ N_h \left(\frac{\theta(\alpha+\gamma)}{2\gamma} \left(\sqrt{\frac{4\alpha\gamma L_f}{\theta N_h (\alpha+\gamma)^2} + 1} - 1 \right) + 1 \right) &= \Lambda\left(L_f, \theta, N_h\left(L_h, \pi, R\right)\right) \end{aligned}$$

The partial derivatives are $\frac{\partial \Lambda}{\partial L_f} = \Lambda_{L_f} > 0$ (by inspection), $\Lambda_{N_h}, \Lambda_\theta > 0$ (Figures 1a and 1b), $\Lambda_{L_h} = \Lambda_{N_h} \cdot \frac{\partial N_h}{\partial L_h} = \Lambda_{\theta N_h} \cdot 1 > 0$, $\Lambda_\pi = \Lambda_{N_h} \cdot \frac{\partial N_h}{\partial \pi} = \Lambda_{N_h} \cdot R \left(\frac{x^\delta}{\bar{Q}}\right)^{1/\beta} > 0$, and $\Lambda_R = -\Lambda_{N_h} \cdot (1-\pi) \left(\frac{x^\delta}{\bar{Q}}\right)^{1/\beta} < 0$.

7.2 Proof of Proposition 3:

On the basis of (28) and (29), we have the following comparative statics results: a) $\frac{\partial R^*}{\partial K} = \left(\frac{gr}{K\lambda\phi - gr}\right)^2 > 0$; $\frac{\partial R^*}{\partial r} = -K^2 \frac{g\lambda\phi}{(gr-K\lambda\phi)^2} > 0$ (since $g < 0$); $\frac{\partial R^*}{\partial \phi} = \frac{K^2 gr\lambda}{(K\lambda\phi-gr)^2} < 0$; $\frac{\partial R^*}{\partial g} = -\frac{K^2 r\lambda\phi}{(gr-K\lambda\phi)^2} < 0$. b) The comparative statics results for L^* are: $\frac{\partial L^*}{\partial K} = \frac{-gr^2\phi}{(K\lambda\phi-gr)^2} > 0$; $\frac{\partial L^*}{\partial r} = \frac{r^2\phi}{(K\lambda\phi-gr)^2} > 0$; $\frac{\partial L^*}{\partial \phi} = \frac{-Kgr^2}{(K\lambda\phi-gr)^2} > 0$; $\frac{\partial L^*}{\partial g} = \frac{K^2\lambda\phi^2}{(gr-K\lambda\phi)^2} > 0$.

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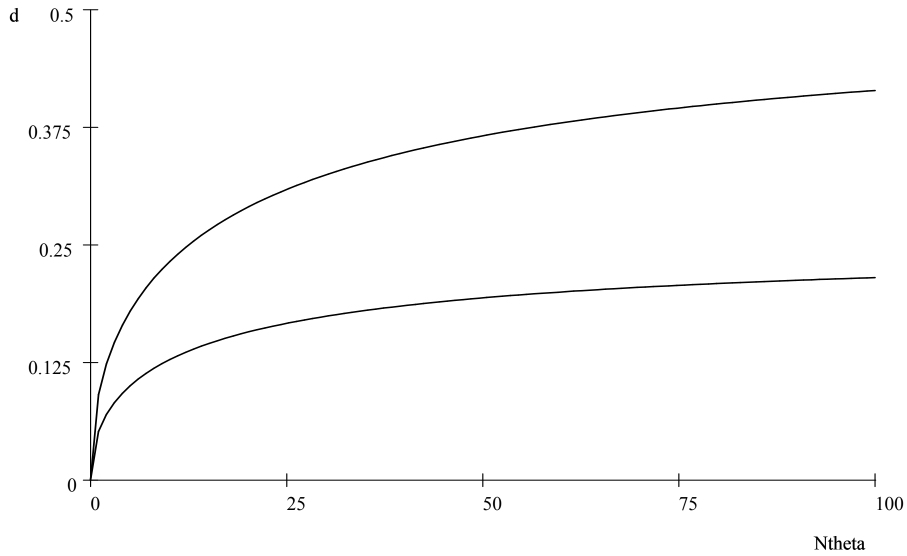
Figure 1: Best response defensive efforts by farmers (*d*) as a function of effective offensive efforts by herders (*Ntheta*) at varying parameter values.



Note: Calculations are based on the best response function in eq. (25). The example with the solid line assumes $\alpha = \gamma = 1/2$ and $L_f = 100$, whereas the dotted line assumes $\alpha = 1/4$, $\gamma = 3/4$ and $L_f = 100$.

Figure 2a: Long-run dynamics of resources and population

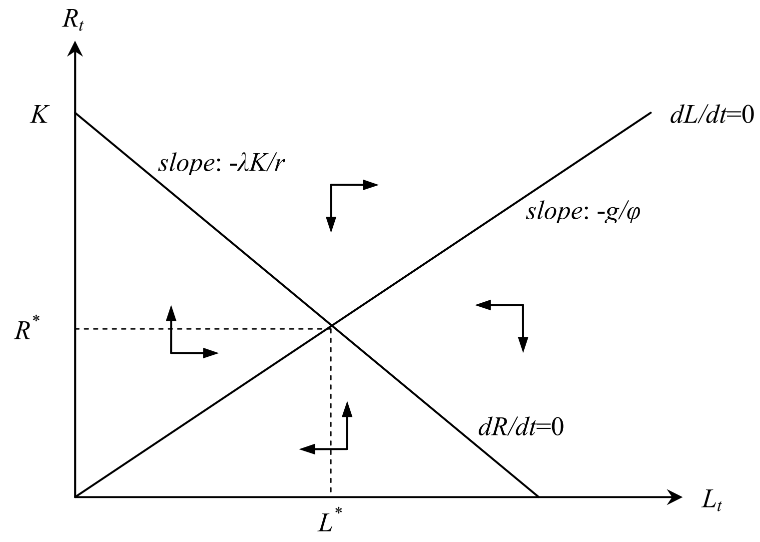


Figure 2b: Transition dynamics towards steady-state following a resource per capita shock and long-run climate deterioration

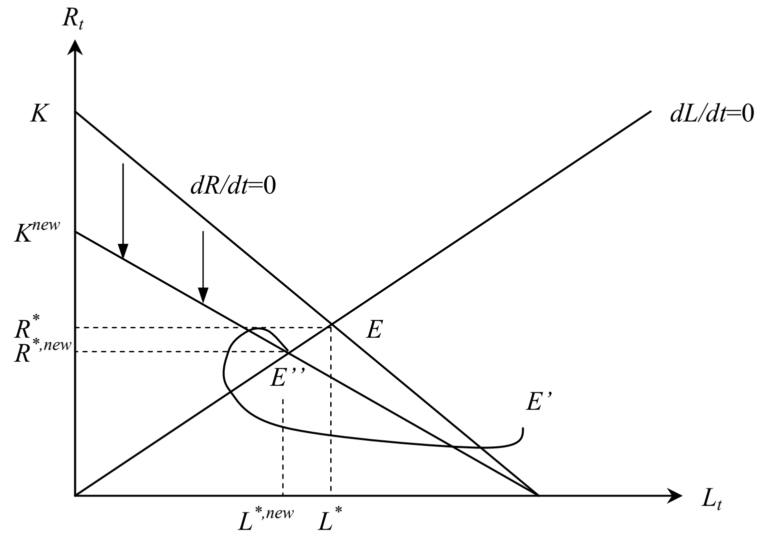
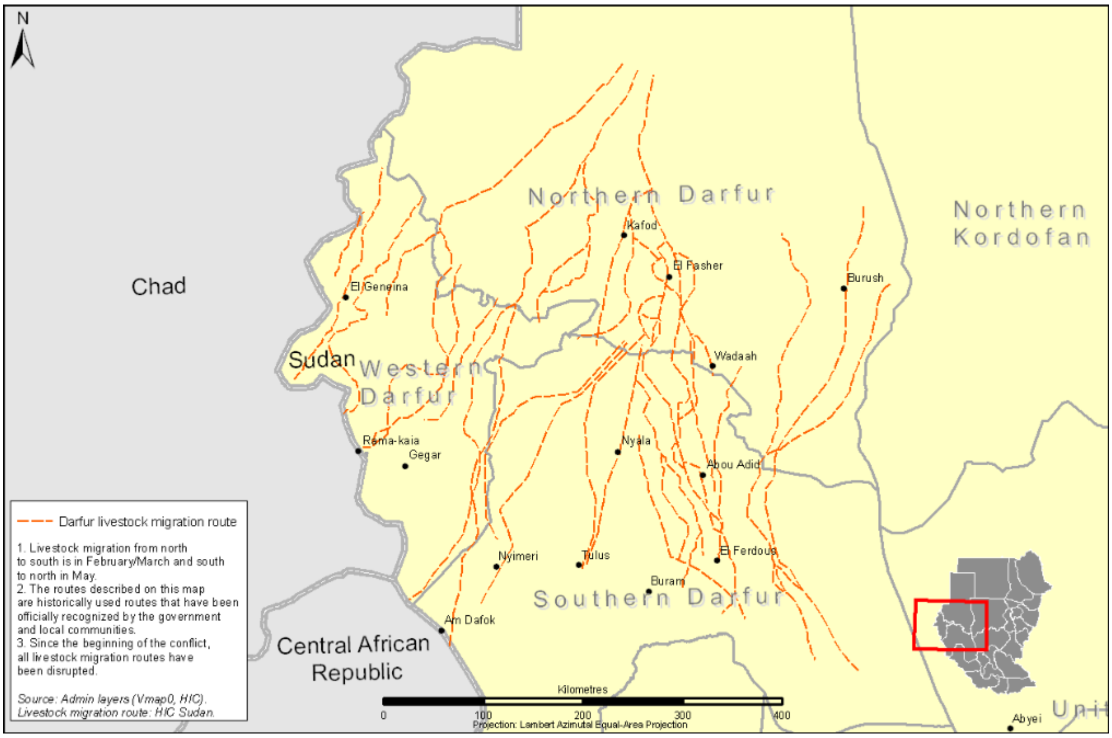


Figure 3: Conflict areas in Sudan, 2008.

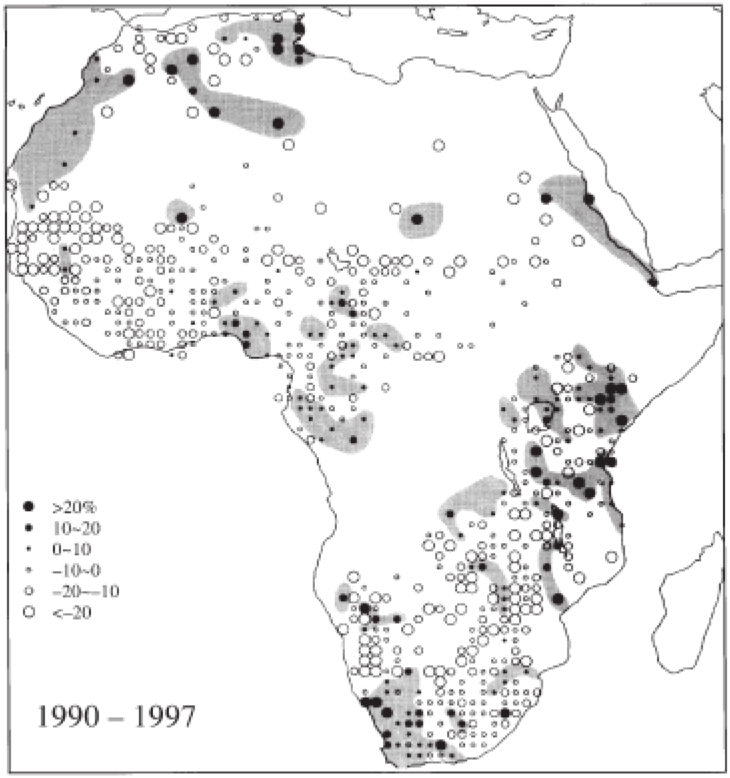
Source: UNEP (2007)

Figure 4: Livestock migration routes through Darfur



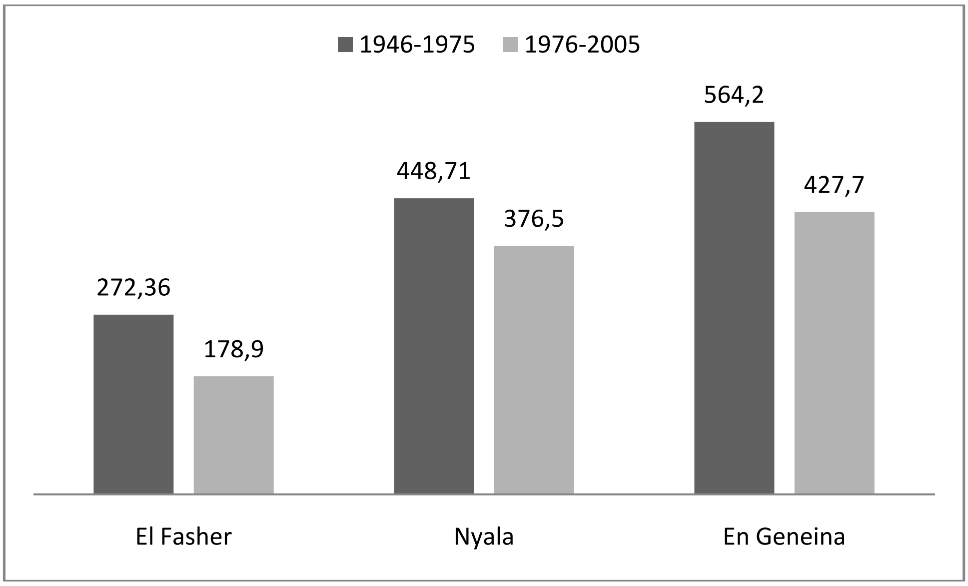
Source: UNEP (2007)

Figure 5: Precipitation in Africa as a percentage departure from the long-term mean, 1990-97



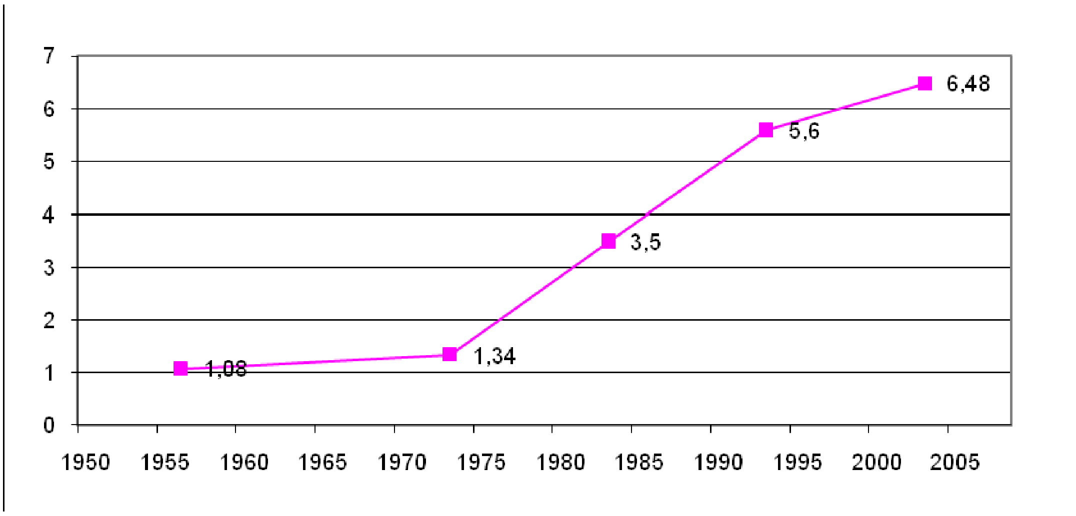
Source: Nicholson (2001)

Figure 6: Average precipitation (in mms) in the three Darfuri capitals by time period.



Source: Constructed on the basis of data from UNEP (2007, Table 4).

Figure 7: Total population levels (in millions) in Darfur, 1956-2003.



Source: Constructed on the basis of data from D-JAM (2006, p 12)