

# **Analyzing and Addressing Localized Degradation in the Commons**

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Running Head: Localized Degradation

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### **ABSTRACT**

Economists have argued that commonly held African rangelands are suffering widespread degradation due to overstocking. However, in many areas, degradation is localized rather than widespread. Current common property models are insufficient for analysis of such degradation. A model is developed identifying conditions leading to spatial differences in rangeland condition. Analysis of longitudinal data on herder land-use decisions follows. Results suggest the herd size reductions recommended by current common property models are of limited effectiveness in combating localized degradation due to user and resource heterogeneity. Directly addressing incentives leading to poor spatial distribution of livestock is proposed as an alternative.

Keywords: localized degradation, pastoralism, simulated maximum likelihood, bivariate tobit.

## INTRODUCTION

The record of efforts supporting livestock production in arid and semi-arid areas of Africa is disappointing [13,5,22]. Scoones [35] describes this failure in stark terms. “Millions of dollars have been spent with few obvious returns and not a little damage. Most commentators agree that the experience has been a disaster...” (p. 3)

A major objective of pastoral development efforts has been to address rangeland degradation brought about by overgrazing. Pastoral production has been described as ecologically destructive due to the long term impact of livestock accumulation on rangeland condition [6,10,19,21]. Doran, Low and Kemp [10] suggest “the tendency to retain or increase cattle numbers even under adverse environmental conditions is a widespread and characteristic feature of many African societies. The observation that Africa is now perhaps the classic example of a continent suffering from soil erosion caused by overgrazing is a reflection of the nature and extent of the problem” (p.41). They find “...it will be necessary either to implement measures that will induce stockowners to sell more cattle or, alternatively, to enforce control of cattle numbers.”(p.45).<sup>1</sup>

Recent range ecology research suggests the environmental assessment that underlies this perspective is not applicable to all rangeland areas [18,27,17]. These studies suggest that under the climatic conditions characterizing many arid and semi-arid rangelands in Africa,<sup>2</sup> stocking pressure has little permanent impact on rangeland condition [11,40,3,35]. Environmental conditions make it unlikely that animal numbers reach levels sufficient to cause widespread changes in rangeland condition. Sanford [33] argues that in such areas the economic cost of policies limiting herd size are extremely

high, while Abel [1] and Biot [4] suggest that the environmental benefit of such policies are negligible.

While widespread degradation of arid and semi-arid rangelands may be less of a concern than previously assumed, empirical range ecology studies increasingly associate localized degradation with key resource areas within a given rangeland [24,34,36,9,20,38,39]. Such findings indicate rangeland degradation as it is occurring in many areas of arid and semi-arid Africa is at least as much a result of the spatial distribution of animals as it is a result of the number of animals using a rangeland. As the spatial distribution of livestock reflects management decisions made by herders, addressing localized degradation requires understanding the land-use decisions made by pastoralists.

This study investigates herder land-use decisions. By explicitly incorporating herder and rangeland heterogeneity into the analysis, it is shown that policies reducing aggregate herd size are of limited effectiveness in addressing localized degradation. In some cases such policies can even increase stocking pressure in areas identified as being in poor condition. This occurs because use of degraded rangeland areas increases as a household's herd size decreases.

In a broader sense, this study describes how household level exploitation decisions respond to incentives arising from the heterogeneous nature of a shared resource. It also describes how household level heterogeneity influences these decisions. Results suggest policies modifying land-use incentives present an alternative to reducing aggregate exploitation levels if the objective is to reduce localized over-exploitation.

The outline of this paper is as follows. The next section presents a description of evidence on rangeland degradation in the study area, followed by a discussion of the production system prevalent in the study area. A model exploring conditions that can lead to localized differences in rangeland condition is then presented. Empirical analysis of land-use decisions follows. A summary and conclusion is presented in the final section of the paper.

#### EVIDENCE ON RANGELAND DEGRADATION IN THE STUDY AREA

Marsabit District, Kenya is particularly suited to the objectives of this study as there has been a long-standing concern about rangeland degradation in this area. The UN funded Integrated Project in Arid Lands (IPAL) was active in this area from 1976 to 1983 “...with the aim of finding direct solutions to the most urgent environmental problems associated with desert encroachment and ecological degradation.” (introduction, [24]). These environmental problems proved more nuanced than the project originally anticipated. Little [23] states, “while IPAL’s environmental studies rate much of Marsabit District as degraded or under threat of degradation, the project’s data show that most of the degradation has been in the vicinity of a few large settlements...even in the case of the settlements, IPAL admits that much of the damage is probably reversible”(p.232). O’Leary [29], a former member of the IPAL research team, states that in the final analysis “IPAL range and livestock scientists calculated that generally at the macro-level, the range sources could support current livestock populations. Range degradation is confined to areas surrounding trading centers and permanent water; but this is compensated by vast areas which are underutilized” (p.65).

O’Leary’s impressions are consistent with a 1988 assessment of the District’s rangelands reported in the Range Management Handbook of Kenya [34]. This evaluation categorizes 80% of the rangeland areas as good (not degraded), 18% as fair (showing impact of use by livestock below a level seriously impairing livestock productivity), and 2% of the rangeland is poor or very poor (exhibiting significant decreases in productivity attributable to overuse). These overused areas are almost all within a five-hour walk of the small market towns in the District.

Evidence that the District’s total rangelands have not been overstocked in ecological terms can be obtained by comparing livestock population estimates with the Range Management Handbook’s maximum stocking rate guidelines. Figure one indicates that no year from 1963-1998 for which data are available is characterized by ecological overstocking when the District is taken as a whole. This suggests that the degradation problems identified in this area have resulted from a sub-optimal spatial distribution of livestock, rather than a larger than optimal herd size. Analyzing and addressing localized degradation thus requires understanding of factors influencing pastoralist land-use decision making, to which this study now turns.

[insert figure I]

## GABRA PASTORALISM

Gabra nomads are herders of camels, cattle, sheep and goats. Rain-fed agriculture is not possible in the vast majority of the study area, as median annual rainfall is between 100-200 mm. Therefore, households rely on livestock and livestock products almost

completely for meeting their consumption needs, either through home consumption or through market exchange.

Marketing offers herders advantageous terms of trade in terms of meeting subsistence needs. For an equal cash value of the respective products, the grain : meat caloric ratio was 4:1 and the grain : milk caloric ratio was 6:1 during the study period. However, taking advantage of these terms of trade can be difficult, as marketing takes place almost exclusively in the towns of the study area, which are only reachable by herders if they walk to these locations.

Further understanding of Gabra household economy can be derived by considering sources of consumption revealed in the data collected for this study. If market values are assigned to all home consumed goods, on average 61% of consumption is from home consumed milk, 21% is from market goods purchased through livestock sales, 15% is from home consumed meat, and the remaining 3% is accounted for by food aid or market goods purchased by milk sales, hide sales, or gifts. The average cash value of consumption per-person per-day is equivalent to \$0.78, suggesting the average herder is below a \$1 per-person per-day poverty line.

The nomadic nature of the Gabra production system is reflected by two separate land-use decisions: a base camp decision and a satellite camp decision. By selecting a base camp site and by sending animals and laborers to a satellite camp, the herder selects areas the household herd will graze as well as the distance household members will be required to walk to take advantage of markets and services in the nearest town. Satellite camps are more mobile than base camps, and are designed to make use of pasture in rangelands considered remote. Herders prefer to use satellite camps when possible as

herds in these camps are described as more productive and capable of faster growth than herds in base camps. Herders usually send a portion of their total herd and labor force to satellite camps located between 25 km and 200 km from the base camp. Due to the distance these camps are located from market towns, herders in satellite camp rely on a diet of milk and meat almost exclusively.

Empirical evidence from the study area indicates aggregate range resources have been sufficient to support total livestock populations in ecological terms. However, particular rangeland sub-areas have been identified as degraded. These facts are reconciled by suggesting a sub-optimal spatial distribution of animals has taken place within the rangelands of Marsabit District. Pastoralist land-use decisions determine the spatial distribution of animals, and are influenced by production and consumption incentives facing herders. Analyzing and addressing this degradation requires development of a framework recognizing both heterogeneity in rangeland sub-areas and the importance of land-use decisions.

#### A MODEL OF HETEROGENEOUS RANGELAND-USE

The premise of static “tragedy of the commons” models is that each individual chooses a privately optimal use level. In the case of commonly used rangelands, the individual is often modeled as selecting a privately optimal herd size. However, in the production context facing many herders in dryland Africa, the ability of an individual to select a herd size is severely limited.<sup>3</sup> The individual’s choice in this production environment is more accurately cast as offtake from a given herd rather than choice of herd size. This requires development of a dynamic model of livestock accumulation. The

core of the model developed in this section is similar to Clark, Clarke and Munro's [7] model in that private capital is required to exploit a shared renewable resource.

Rangeland degradation is also best modeled as a dynamic process. An innovation of the current study is that it allows rangeland sub-areas to follow different evolutionary paths. In the economics literature, heterogeneity in a shared renewable asset has not been explicitly modeled, although Swallow [37] models the development of heterogeneous non-renewable resources that contribute to the production of renewable resources. The objective of this section is to identify generalized conditions under which rangeland sub-areas will differ in long-run productive potential.

Define the productive potential of two separate rangeland sub-areas at time  $t$  by  $y_{1t}$  and  $y_{2t}$ . The area characterized by  $y_{1t}$  is termed area one while the area characterized by  $y_{2t}$  is termed area two. Assume individuals  $i=1, \dots, n$  share access to these two rangeland sub-areas  $\forall t$ . This shared access allows each individual  $i$  at time  $t$  to place his entire herd of size  $k_t^i$  somewhere within these two rangeland sub-areas. The decision on allocating a share of this herd to a particular sub-area is recorded by the choice variable  $s_t^i$ . This variable records the share of the herd in time  $t$  placed in rangeland area one and implicitly defines the share allocated to area two by  $1 - s_t^i$ .<sup>4</sup>

Individual  $i$  also chooses an offtake level  $ot_t^i$  from herd  $k_t^i$  at time  $t$ . Individuals obtain utility from consumption at time  $t$  defined by  $c_t^i$ . Consumption is comprised of the offtake level from the herd, production from the herd, and amenities available in a particular rangeland sub-area. Under the assumption that area one contains a market town, define the contribution of offtake to consumption by  $((\pi^{ot} - 1) \cdot s_t^i + 1) \cdot ot_t^i$ , where

$\pi^{ot} \geq 1$ . This assumes that offtake in area one is sold in exchange for market goods at the fixed price ratio  $\pi^{ot}$ , while offtake in area two is directly consumed at the numeraire price. In a similar fashion, assume milk produced in area one is marketed at a fixed price ratio  $\pi^m \geq 1$  while milk produced in area two is directly consumed at the numeraire price. The production of milk in a given sub-area is specified to be a function of the size of the individual's herd allocated to a sub-area and the condition of the rangeland in that sub-area. If the production function is represented in Cobb-Douglas form, the contribution of milk to consumption can be represented as  $\pi^m \cdot \tau_{10} (s_t^i \cdot k_t^i)^{\tau_{11}} (y_{1t})^{1-\tau_{11}}$  +  $\tau_{20} ((1-s_t^i) \cdot k_t^i)^{\tau_{21}} (y_{2t})^{1-\tau_{21}}$ , where  $\pi^m \geq 1, \tau_{10} \geq 0, \tau_{20} \geq 0, \tau_{11} \leq 1, \tau_{21} \leq 1$ . Finally, assume area one offers amenities that are only accessible during time spent in this sub-area. Define the total value of these amenities by a constant  $am \geq 0$ , so that the contribution of amenities to consumption is  $am \cdot s_t^i$ .

$$U(c_t^i) = U \left[ \begin{array}{l} ((\pi^{ot} - 1) \cdot s_t^i + 1) \cdot ot_t^i + \\ \pi^m \cdot \tau_{10} (s_t^i \cdot k_t^i)^{\tau_{11}} (y_{1t})^{1-\tau_{11}} + \tau_{20} ((1-s_t^i) \cdot k_t^i)^{\tau_{21}} (y_{2t})^{1-\tau_{21}} + \\ am \cdot s_t^i \end{array} \right] \quad (1)$$

where  $\partial U / \partial c_t^i > 0, \partial^2 U / \partial c_t^i{}^2 \leq 0, \lim_{c \rightarrow 0} \partial U / \partial c = \infty, \lim_{c \rightarrow \infty} \partial U / \partial c = 0$ .

The model defines herd growth as a function of the size of the individual's herd and the state of the rangeland. Define Cobb Douglas herd growth functions for herder i's herd at time t in area one is  $\alpha_{10} (s_t^i \cdot k_t^i)^{\alpha_{11}} (y_{1t})^{1-\alpha_{11}}$  while in area two it is  $\alpha_{20} ((1-s_t^i) \cdot k_t^i)^{\alpha_{21}} (y_{2t})^{1-\alpha_{21}}$ . Together, the starting period herd size, the share of time allocated to each sub-area, the offtake decision, and the growth functions determine next period's herd size according to the following state equation.

$$k_{t+1}^i = k_t^i + \alpha_{10} (s_t^i \cdot k_t^i)^{\alpha_{11}} (y_{1t})^{1-\alpha_{11}} + \alpha_{20} ((1-s_t^i) \cdot k_t^i)^{\alpha_{21}} (y_{2t})^{1-\alpha_{21}} - ot_t^i \quad (2)$$

The variables representing rangeland productive potential evolve according to their current period realizations as well as the herd size and allocation decisions of the  $n$  herders. This evolution is represented by a function that increases future rangeland productive potential if current period stocking level is less than current period rangeland productive potential and a function representing current period extraction by the aggregate herd. The functions governing the evolution of rangeland productive potential in the respective sub-areas are as follows.

$$y_{1t+1} = y_{1t} + \begin{cases} \eta_{10} \cdot (y_{1t} - \sum_n s_t^i \cdot k_t^i)^{\eta_{11}} - \varepsilon_1 \cdot \sum_n s_t^i \cdot k_t^i & \text{if } y_{1t} \geq \sum_n s_t^i \cdot k_t^i \\ -\varepsilon_1 \cdot \sum_n s_t^i \cdot k_t^i & \text{if } y_{1t} < \sum_n s_t^i \cdot k_t^i \end{cases} \quad (3a)$$

$$y_{2t+1} = y_{2t} + \begin{cases} \eta_{20} \cdot (y_{2t} - \sum_n (1-s_t^i) \cdot k_t^i)^{\eta_{21}} - \varepsilon_2 \cdot \sum_n (1-s_t^i) \cdot k_t^i & \text{if } y_{2t} \geq \sum_n (1-s_t^i) \cdot k_t^i \\ -\varepsilon_2 \cdot \sum_n (1-s_t^i) \cdot k_t^i & \text{if } y_{2t} < \sum_n (1-s_t^i) \cdot k_t^i \end{cases} \quad (3b)$$

where  $\eta_{10} \geq 0, \eta_{20} \geq 0, \eta_{11}, \eta_{21} \in (0,1), \varepsilon_1 \geq 0, \varepsilon_2 \geq 0$ .

The utility of consumption is additively separable over time. Future consumption is discounted by  $(1+r)^{-1} \in [0,1]$ , where  $r$  is a measure of the discount rate. The individual is assumed to form Nash best response strategies to the actions and herd sizes of the other  $(n-1)$  herders. Taken together, the individual's problem can be written in the following Bellman's form.

$$V[k_t^1, \dots, k_t^n, y_{1t}, y_{2t}] = \text{Max}_{ot_t^i, s_t^i} U(c_t^i) + (1/(1+r)) \cdot V[k_{t+1}^1, \dots, k_{t+1}^n, y_{1t+1}, y_{2t+1}] \quad (4)$$

s.t. (1), (2), (3a),(3b),  $y_{10}, y_{20}, k_0^i \forall i = 1, \dots, n$  given,  $t=0, \dots, \infty$ .

Consider the first order condition with respect to the share choice variable.

$$\begin{aligned}
\frac{\partial V}{\partial s_t^i} = 0 = & \left( \frac{\partial U}{\partial c_t^i} \left( \pi^{ot} ot_t^i + am + \left( \pi^m \tau_{10} \tau_{11} \left( \frac{y_{1t}}{s_t^i k_t^i} \right)^{1-\tau_{11}} - \tau_{20} \tau_{21} \left( \frac{y_{2t}}{(1-s_t^i) k_t^i} \right)^{1-\tau_{21}} \right) k_t^i \right) + \right. \\
& \left. \left( \frac{1}{1+r} \right) \frac{\partial V}{\partial k_{t+1}^i} \left( \alpha_{10} \alpha_{11} \left( \frac{y_{1t}}{s_t^i k_t^i} \right)^{1-\alpha_{11}} - \alpha_{20} \alpha_{21} \left( \frac{y_{2t}}{(1-s_t^i) k_t^i} \right)^{1-\alpha_{21}} \right) k_t^i + \right. \\
& \left( \frac{1}{1+r} \right) \frac{\partial V}{\partial y_{2t+1}} \left( \eta_{20} \eta_{21} (y_{2t} - \sum_n (1-s_t^i) k_t^i)^{\eta_{21}-1} - \varepsilon_2 \right) k_t^i - \\
& \left. \left( \frac{1}{1+r} \right) \frac{\partial V}{\partial y_{1t+1}} \left( \eta_{10} \eta_{11} (y_{1t} - \sum_n s_t^i k_t^i)^{\eta_{11}-1} - \varepsilon_1 \right) k_t^i \right)
\end{aligned} \tag{5}$$

Equation (5) shows that the herder's share decision balances the impact on consumption, herd growth, and rangeland condition of allocating a larger fraction of a given herd to area one. A higher share  $s_t^i$  of herd  $k_t^i$  will be allocated to area one under any of the following conditions.

- 1) The contribution of offtake to consumption is greater if it is marketed ( $\pi^{ot} > 1$ )
- 2) The contribution of milk to consumption is greater if it is marketed ( $\pi^m > 1$ )
- 3) Amenities available in area one are not available in area two ( $am > 0$ )
- 4) Milk production is inherently higher in area one than area two ( $\tau_{10} > \tau_{20}$ )
- 5) Livestock growth is inherently higher in area one than area two ( $\alpha_{10} > \alpha_{20}$ )
- 6) Area one has higher rangeland productive potential than area two ( $y_{1t} > y_{2t}$ ).

It also can be seen that herd size differences between individuals under conditions 2 - 6 will influence the share variable, as  $k_t^i > k_t^j \Rightarrow s_t^i \geq s_t^j$ .

These results indicate that observed differences in use patterns can result from differences in rangeland characteristics or differences in household wealth. In order to focus on the long run implications of differences in rangeland characteristics, the equations governing the optimal solution for this problem are solved by assuming an interior symmetric steady state solution exists. In steady state, area one will be less intensively used than area two ( $s < (1-s)$ ), and rangeland productive potential in area one will be less than that found in area two ( $y_1 < y_2$ ), under conditions 1 - 5.

The model suggests differences that observed in rangeland condition in different areas can be understood as the result of land-use decisions made by herders. It is also found that differences in herd size influence land-use decisions. The following section presents an empirical analysis of land-use decisions.

## EMPIRICAL ANALYSIS OF LAND-USE DECISIONS

Data for this study were gathered from 39 Gabra nomadic households in the Chalbi basin of Marsabit District, Kenya. The data set records household specific information for four time periods (two rainy seasons and two dry seasons) per-year from 1993 to 1997.<sup>5</sup> The longitudinal nature of the data allows empirical exploration of how land-use decisions made by users of a common rangeland change in response to changes in the state of nature as well as changes in the household's own characteristics.

The data gathering methodology was retrospective, and the sampling framework was based on a transect, rather than sampling from a population list. As Gabra are nomadic herders, the logistics involved with random sampling were prohibitively expensive. As seven of the households have incomplete information in certain periods, and some households were interviewed later in 1997 than were others, the longitudinal data set used in the estimation is unbalanced.

The focus of the analysis presented in this section is recovery of empirical decision rules corresponding to the share variable  $s_t^i$  in the model presented in the previous section. However, the estimation methodology expands the concept of rangeland sub-areas from the two-area model presented above. Gabra rangelands are conceived of being composed of multiple sub-areas. The defining characteristic of a sub-

area in the estimation procedure is the hours it takes to walk from this area to the nearest market town.<sup>6</sup> A herder's base camp location decision in this way reflects the choice variable of the model presented above. However, as noted in the discussion of the Gabra production system, herders also make use of satellite camps in rangelands considered remote. This is represented by a separate decision rule which records the share of the household labor force sent to remote camps. A herder's decision to send labor to a satellite camp can be viewed as sending animals to the furthest rangeland sub-area.<sup>7</sup> Together these variables capture decisions that determine the share of a herder's animals allocated to different rangeland sub-areas.

As discussed above, markets and services are concentrated in market towns. As the terms of trade between pastoral and non-pastoral products were relatively stable from 1993 to 1997, the study is unable to investigate how changes in these terms influence land-use decisions. This is also true for most amenities such as schools and health centers that did not vary during the period under study. However, amenities such as the importance of security services and food aid availability did change over time. As using rangelands away from town may be decreased due to fears of raids, a dummy variable that records periods when raids occurred is included in the estimation procedure.<sup>8</sup> A variable measuring the total food aid deliveries recorded at the two major towns in the study area is used to reflect food aid availability.<sup>9</sup>

It is not clear whether rangeland sub-areas differ in inherent productivity of milk production or herd growth, but it is clear that the sub-areas differ in productive potential according to the range condition assessment, with areas near towns currently having less productive potential than areas away from towns. For the period under investigation, it is

assumed this difference can be viewed as constant. However, realized rangeland production does change over the study period. Four variables are used to capture these changing conditions. The first records rainfall over the past six months, as rainfall clearly influences pasture production. The second and third are dummy variables indicating whether period  $t$  is in the annual long rains or short rains as there is a seasonality to pasture production. The fourth records a ratio of the herder's subjective evaluation of the relative pasture availability in the area near town divided by a similar subjective evaluation of the pasture availability in the area away from town.<sup>10</sup> This variable reflects both spatial differences in pasture production and the land-use decisions made by other herders.<sup>11</sup>

Household characteristics may also influence land-use decisions. A quadratic representation of the age of the household head is utilized, as is a measure recording the size of the household in adult equivalents.<sup>12</sup> As suggested by the model, use patterns may also be impacted a household's herd size. A quadratic representation of a household's animal wealth is captured by a measure of the Total Livestock Units (TLUs) in household  $i$ 's herd at time  $t$ .<sup>13</sup> Also included is a measure of the number of pack camels available to a household, as migration may be facilitated by baggage animals.

Table I reports the descriptive statistics of the variables used in the estimation.

[Insert Table I]

Three major issues must be confronted in the estimation methodology. First, both dependent variables are by definition non-negative and have a significant number of observations at zero (7% for the distance variable, 53% for the satellite camp variable).

Second, the two decision variables are obviously related to each other. Third, the data set is longitudinal in nature.

The first two issues can be confronted by use of simultaneous tobit estimation methodology following Amemiya [2] and Maddala [25]. However, account must be taken of the correlation in unobserved terms that could result due to the longitudinal nature of the data. Adopting Mundlak's [28] suggestion, define a household specific effect by  $a_i = \lambda' \bar{x}_i + \omega_i$ , where  $\bar{x}_i$  records the mean of household specific variables for household  $i$ ,  $t=1, \dots, T$  and  $\omega_i \sim N(0, \sigma_\omega^2)$ . Define  $d$  as the distance from town variable,  $sat$  as the satellite camp variable,  $\gamma$  as coefficients on endogenous variables,  $x$  as exogenous variable matrices,  $\beta$  as coefficients on exogenous variables, and  $u$  as unobserved terms. Define the following model, where  $i$  indexes households and  $t$  indexes time.

$$\begin{aligned}
 d_t^i &= \gamma_1 sat_t^i + \beta_1' x_{1t}^i + a_{1i} + u_{1t}^i & \text{if } RHS > 0 \\
 d_t^i &= 0 & \text{if } RHS \leq 0 \\
 sat_t^i &= \gamma_2 d_t^i + \beta_2' x_{2t}^i + a_{2i} + u_{2t}^i & \text{if } RHS > 0 \\
 sat_t^i &= 0 & \text{if } RHS \leq 0
 \end{aligned} \tag{6}$$

Four possible regimes exist in this model. Define these as follows: Regime

1  $d_t^i > 0, sat_t^i > 0$ ; Regime 2  $d_t^i > 0, sat_t^i = 0$ ; Regime 3  $d_t^i = 0, sat_t^i > 0$ ; Regime 4  $d_t^i = 0, sat_t^i = 0$ .

Define the joint density of  $u_{1t}^i, u_{2t}^i$  by  $f(u_{1t}^i, u_{2t}^i)$ . Then the likelihood function for this model can be written as follows.

$$\begin{aligned}
 L &= \prod_1 (1 - \gamma_1 \gamma_2) f(d_t^i - \gamma_1 sat_t^i - \beta_1' x_{1t}^i - a_{1i}, sat_t^i - \gamma_2 d_t^i - \beta_2' x_{2t}^i - a_{2i}) \\
 &\quad \prod_2 \int_{-\infty}^{-\gamma_2 d_t^i - \beta_2' x_{2t}^i - a_{2i}} f(d_t^i - \beta_1' x_{1t}^i - a_{1i}, u_{2t}^i) du_2 \\
 &\quad \prod_3 \int_{-\infty}^{-\gamma_1 sat_t^i - \beta_1' x_{1t}^i - a_{1i}} f(u_{1t}^i, sat_t^i - \beta_2' x_{2t}^i - a_{2i}) du_1 \\
 &\quad \prod_4 \int_{-\infty}^{-\beta_2' x_{2t}^i - a_{2i}} \int_{-\infty}^{-\beta_1' x_{1t}^i - a_{1i}} f(u_{1t}^i, u_{2t}^i) du_1 du_2
 \end{aligned} \tag{7}$$

If  $f(u_{1t}^i, u_{2t}^i)$  is assumed to be bivariate normal, one can use the fact that the conditional expectation of a normally distributed variable is itself normal. This allows the joint distribution in regimes two and three to be separated into a probability density component and a cumulative density component.

Recalling that each equation's household specific effect includes a random effect term  $\omega_i$ , direct estimation of all  $(2 \times n)$  of these terms severely limits the degrees of freedom in the model. An alternative is to use simulated maximum likelihood [14,15]. The simulation requires that  $H$  representations of the  $[\omega_{1i}, \omega_{2i}]$  vector are generated for use in the estimation procedure. Assume that  $\omega_{1i}$  is drawn from a  $N(0, \sigma_{\omega_1}^2)$  distribution and  $\omega_{2i}$  is drawn from a  $N(0, \sigma_{\omega_2}^2)$  distribution. To create an empirical analog to this assumption,  $(n, H)$  pseudo-random draws from two separate  $N(0, 1)$  distributions are taken. All  $t=1, \dots, T$  observations for household  $i$  in draw  $h$  are assigned a unique pair of these draws. The  $2 \times (n, H)$  draws are multiplied by a  $(2 \times 1)$  scaling parameter vector  $\delta$ . The parameter  $(\delta_1)^2$  provides an estimate of  $\sigma_{\omega_1}^2$ , and  $(\delta_2)^2$  provides an estimate of  $\sigma_{\omega_2}^2$ .

If  $\phi, \Phi$  and  $f_{bvn}, F_{bvn}$  are used to represent the p.d.f. and c.d.f of the standard normal and the bivariate normal respectively, the log likelihood function used in the estimation can be written as follows.

$$\sum_{i=1}^n \ln \left[ \frac{1}{H} \sum_{h=1}^H \left( \begin{array}{l} \prod_{1,t=1}^T f_{\text{bvn}}(d_t^i - \gamma_1 \text{sat}_t^i - \beta_1' x_{1t}^i - a_1, \text{sat}_t^i - \gamma_2 d_t^i - \beta_2' x_{2t}^i - a_2, \sigma_d^2, \sigma_{\text{sat}}^2, \rho) \\ \prod_{2,t=1}^T \frac{1}{\sigma_d} \phi \left( \frac{d_t^i - \beta_1' x_{1t}^i - a_1}{\sigma_d} \right) \Phi \left( \frac{(-\gamma_2 d_t^i - \beta_2' x_{2t}^i - a_2) - \left( \frac{\sigma_{d,\text{sat}}}{\sigma_d^2} \right) (d_t^i - \beta_1' x_{1t}^i - a_1)}{(\sigma_{\text{sat}}^2 - (\sigma_{d,\text{sat}}^2 / \sigma_d^2))^{1/2}} \right) \\ \prod_{3,t=1}^T \frac{1}{\sigma_{\text{sat}}} \phi \left( \frac{\text{sat}_t^i - \beta_2' x_{2t}^i - a_2}{\sigma_{\text{sat}}} \right) \Phi \left( \frac{(-\gamma_1 \text{sat}_t^i - \beta_1' x_{1t}^i - a_1) - \left( \frac{\sigma_{d,\text{sat}}}{\sigma_{\text{sat}}^2} \right) (\text{sat}_t^i - \beta_2' x_{2t}^i - a_2)}{(\sigma_d^2 - (\sigma_{d,\text{sat}}^2 / \sigma_{\text{sat}}^2))^{1/2}} \right) \\ \prod_{4,t=1}^T F_{\text{bvn}}(-\beta_1' x_{1t}^i - a_1, -\beta_2' x_{2t}^i - a_2, \sigma_d^2, \sigma_{\text{sat}}^2, \rho) \end{array} \right) \right] \quad (8)$$

Gourieroux and Monfort [14] state that provided  $n$  and  $H$  go to infinity in such a way that  $\sqrt{n}/H \rightarrow 0$ , the parameters resulting from this estimation are consistent and asymptotically efficient. In the results presented below,  $n=39$ ,  $H=500$ .

[Insert table II]

The parameters for the endogenous variables satisfy the coherency condition described by Amemiya [2], and indicate that herders view increasing distance from town and increased use of satellite camp as substitutes. The Wald test results indicate the fixed effect coefficients<sup>14</sup> are jointly significant for the satellite camp equation, but not so for the base camp decision, while the random effect scaling parameter is significant for both equations. The unobserved terms for the two equations exhibit a correlation of 0.75.

There is a seasonality of decisions captured by the rainy season dummy variables, indicating use of areas near town increases during rainy seasons.<sup>15</sup> It is also seen that use of satellite camps increases in response to relatively low rainfall realizations over a six month period, though rainfall levels have no significant impact on the base camp

decision. Although the ratio of a herder's pasture availability ranking for the two zones is of the expected sign for both equations, it is not significant in either case.

While the security amenity associated with proximity to town does not significantly influence land-use decisions, the food aid delivery variable has a significant effect on satellite camp use, suggesting that the availability of food aid decreases the use herders make of extensive grazing areas.

Of particular interest in these results is that as a household's herd size increases, both the distance from town a base camp settles and the use of a satellite camp increases. This indicates the benefits of using areas away from town in terms of herd production and growth more than compensate large herd owners for the foregone opportunity of spending time near town. Herders argue that owners of larger herds are able to subsist largely on milk and meat without recourse to grain purchase, which is beneficial both in terms of their own dietary preferences<sup>16</sup> and in allowing herders to utilize areas far from market towns that are best suited for their animals' well-being.

The herd size results indicate that reducing herd sizes to address rangeland degradation may be less effective than currently assumed. As use of rangelands distant from towns is correlated with larger herd size, measures decreasing a household's herd size will lead to decreased use of these areas. A destocking simulation was conducted on the estimation results to explore this issue. The destocking policies considered range from a 4% total herd reduction to a 20% total herd reduction, under a "flat tax" where each herder faces an equal percent tax and a "progressive tax" where the rate is an increasing function of the individual's herd size. The policies are considered for the time periods when average household herd size was largest, from late 1994 to mid 1995.

Under a “flat” percentage reduction, the decrease in the herd size near town herd size averages 71% of the total herd reduction. In 12% of cases considered, destocking leads to increased stocking pressure in the area near town. Under a “progressive” percentage reduction, the impact of a destocking policy on stocking pressure near town averages 64% of the total herd reduction, while in 16% of cases considered, destocking leads to increased pressure in the area near town. Recognizing the role of land-use decisions indicates that destocking may have less of an impact than anticipated in areas where degradation is localized rather than widespread, and can in some cases actually increase stocking pressure in the zone of concern.

## SUMMARY AND CONCLUSION

Pastoral herders have long been accused of causing rangeland degradation through livestock over-accumulation. Economic approaches to this problem have relied on Hardin’s [16] tragedy of the commons metaphor to justify limits on allowable stocking levels. Development efforts in the arid and semi-arid areas of Africa based on this perspective have found little success.

This study suggests a reason for the failure of these efforts is that under production conditions prevailing in many African rangelands, the spatial distribution of livestock is more important in determining changes to rangeland condition than is the total herd size. Spatial patterns of resource use can be understood in terms of the incentives and disincentives facing herd owners. It is argued that herders will place more intense pressure on areas conferring benefits, leading to long run differences in rangeland condition.

Although data limitations prevent testing all model implications, empirical results are consistent with model predictions. Results support the contention that herders formulate their land-use patterns in response to differences in rangeland areas, either indirectly in the case of non-time varying town based markets and services or directly in the case of time varying town based food aid distribution.

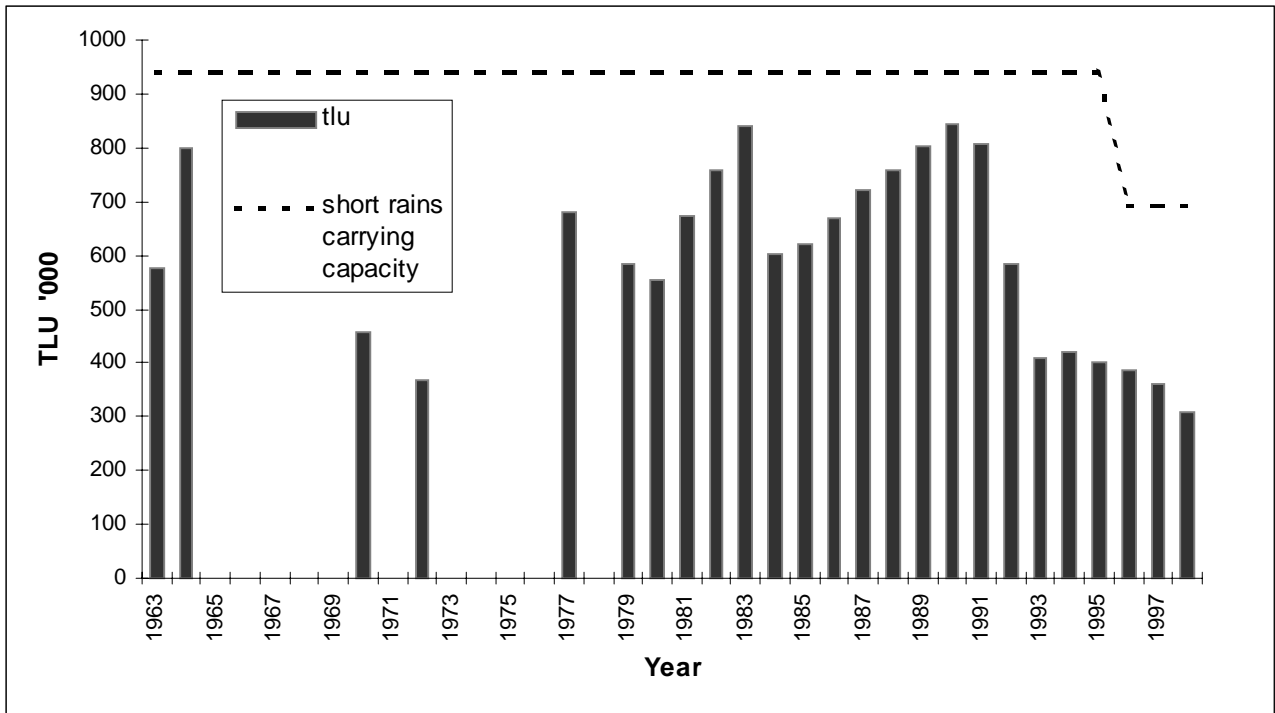
Simulation results show that aggregate herd size reductions may be less effective in addressing degradation than current common property models imply. In fact, it is found that in some cases aggregate herd size reductions have the perverse effect of increasing stocking pressure in degraded areas. The study suggests policy measures other than herd size reductions may be sufficient to address localized degradation. Such policies would modify the incentives currently leading to a sub-optimal spatial distribution of livestock.

Definition of specific policies to address degradation in the study area will require further research aimed at identifying the relative importance of different land-use incentives. This study suggests current policies that distribute food aid from towns could be modified to ease grazing pressure on rangelands near towns. In addition, expanding the ability of herders to market their goods to remote areas could allow them to exploit advantageous terms of trade without creating an incentive to remain near towns. It is also possible that expanding public services to remote areas would confer a similar benefit.<sup>17</sup> Such policies must confront the logistical difficulties that will be involved in expanding benefits to remote areas. In addition, policy definition must ensure that efforts do not lead to an increase in the number of areas of localized degradation rather than the intended effect of addressing localized degradation where it has been identified.

This study finds the relationship between “common property” and “overexploitation” is more complicated than currently understood in the economics literature. Complications arise from two factors. First, users may have heterogeneous ability to capture benefits from a common property resource. Second, the shared resource may itself be heterogeneous. Explicitly incorporating these factors into a common property model leads to new insights into the causes of degradation and policy measures required to address degradation.

The results of this study indicate that a failure to recognize the influence of user and resource heterogeneity may not only undermine the effectiveness of policies to combat degradation, but may also lead the analyst to overlook alternative policy options. The disappointing record of livestock development policies in sub-Saharan Africa is at least partially attributable to a failure to recognize the importance of herder and rangeland heterogeneity in policy design. The broader implication of this study is that policy implications derived from common property models that assume user and resource heterogeneity may be inappropriate if applied to settings that violate these assumptions. If such heterogeneity exists, appropriate policy definition requires explicit attention be paid to the influence of these factors on the common property system under analysis.

Figure One: Estimated Herd Size 1963-1998 Compared to Ecological Carrying Capacity.



Total Livestock Units are calculated by 0.7 camels = 1 head of cattle = 10 sheep or goats. Population estimates are provided in the Range Management Handbook [32] and from the District Livestock Office in Marsabit. Short rains carrying capacity is approximately 1/3<sup>rd</sup> of long rains carrying capacity. The estimated ecological carrying capacity is calculated from information provided in the Range Management Handbook [32]. Moyale District was separated from Marsabit District in 1996. Data from the Moyale District Livestock Office on livestock population is only available for 1998, when total herd size is reported to be 72,000 TLU.

Table I: Means and Standard Deviations of Variables

<b>Variable</b>	<b>Mean</b>	<b>Standard Deviation</b>
<b>Distance base camp to town in hours walk</b>	5.13	4.78
<b>Percent of labor force at satellite camp</b>	0.12	0.15
<b>Rainfall in mm over past six months</b>	58.39	42.09
<b>Long Rains Dummy</b>	0.27	0.45
<b>Short Rains Dummy</b>	0.24	0.43
<b>Ratio of pasture availability in zone one to zone two</b>	0.78	0.26
<b>Raid Dummy</b>	0.43	0.49
<b>Food aid deliveries in tons per period</b>	72.37	88.97
<b>Age of household head</b>	47.12	14.33
<b>Age ratio husband and wife</b>	1.38	0.50
<b>Household size in Adult Equivalents</b>	5.04	2.17
<b>Herd Size (TLU)</b>	42.67	31.13
<b>Number of Pack Camels</b>	2.04	1.74

677 observations, 39 households

Table II: Full Information Simulated Maximum Likelihood Parameter Estimates  
 (standard errors in parentheses, \*, \*\*, \*\*\*, indicate significant at 0.1%, 0.05%, and 0.01% respectively)

	<b>Distance</b>	<b>Satellite Camp</b>
$\gamma_{sat}$	-1.7134 *** (0.3078)	
$\gamma_d$		-0.1680 *** (0.0363)
<b>Constant</b>	-0.1543 (0.2090)	-0.1403 (0.1821)
<b>Rainfall (x10<sup>-2</sup>)</b>	0.3146 (0.5289)	-0.6068 ** (0.2598)
<b>Long Rains Dummy</b>	-0.2542 *** (0.0539)	-0.2183 *** (0.0245)
<b>Short Rains Dummy</b>	0.0219 (0.0445)	-0.0496 ** (0.0189)
<b>Pasture availability ratio (x10<sup>-1</sup>)</b>	-0.3464 (0.7055)	-0.4463 (0.3117)
<b>Raid Dummy</b>	-0.0198 (0.0368)	-0.0031 (0.0161)
<b>Food Aid (x10<sup>-2</sup>)</b>	-0.0300 (0.3115)	-0.2378 * (0.1323)
<b>Age HH head (x10<sup>-2</sup>)</b>	1.9530 (2.4037)	-1.3317 (1.3348)
<b>Age HH head<sup>2</sup> (x10<sup>-4</sup>)</b>	-2.4223 ** (0.9095)	-1.6206 * (0.8346)
<b>Household Size(x10<sup>-1</sup>)</b>	-0.6433 (0.7000)	-0.1837 (0.3008)
<b>Number of Pack Camels</b>	-0.0061 (0.0147)	-
<b>Herd Size (x10<sup>-2</sup>)</b>	0.6499 *** (0.2454)	0.4677 *** (0.1159)
<b>Herd Size (x10<sup>-4</sup>)</b>	-0.1601 ** (0.0759)	-0.1006 ** (0.0391)
<b>Last period Distance</b>	0.4035 *** (0.0427)	-
$\sigma_d$	0.4259*** (0.0166)	
$\sigma_{sat}$		0.1716 *** (0.0075)
$\sigma_{d,sat}$	0.0550 *** (0.0082)	0.0550 *** (0.0082)

$\delta_d$	-0.0929 *** (0.0258)	
$\delta_{\text{sat}}$		0.1250 *** (0.0276)
$\chi^2 \beta = 0$	181.69 ***	140.52 ***
$\chi^2 \lambda = 0$	6.84	29.24 ***
$\chi^2 \lambda = 0, \beta = 0$	601.48 ***	251.33 ***

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List of symbols used in the text.

$y_{1t}$  -rangeland productive potential in zone one at time t

$y_{2t}$  -rangeland productive potential in zone two at time t

$k_t^i$  -herd size of individual i at time t

n - number of individuals / households

$s_t^i$  - share of herd i allocated to zone one at time t.

$\pi^{ot}$  – ratio of market good price to livestock sales price

$\pi^m$  – ratio of market good price to milk sales price

$\tau$  -parameters in milk production function

am- value of amenities to consumption available only in zone one

$c_t^i$  -consumption by individual i at time t

U(.) – utility function

$\alpha$  -parameters in herd growth function

$\eta$  -parameters defining escape function for rangeland productive potential

$\varepsilon$  - parameter of extraction for rangeland productive potential

r - discount rate.

V[.] - value function

$d_t^i$  -distance from town in hours of base camp i at time t

$sat_t^i$  -share of household i's labor force sent to satellite camp at time t

$\gamma_1$  - coefficient for satellite camp in distance of base camp from town equation

$\gamma_2$  - coefficient for distance of base camp from town in satellite camp equation

$\beta_1$  - coefficients for distance from base town equation

$\beta_2$  - coefficients for distance from satellite camp equation

$x_{1t}^i$  -matrix of variables for household i at time t used in base camp equation

$x_{2t}^i$  -matrix of variables for household i at time t used in satellite camp equation

$a_{1t}$  -household specific effect of household i in base camp equation

$a_{2t}$  -household specific effect of household i in satellite camp equation

$\lambda$  -parameters of fixed effect auxiliary regression

$\omega_i$  - random effect for household i

$\sigma_\omega^2$  - variance of random effect terms

$\bar{x}_i$  - matrix of mean of household variables

H- number of draws used in simulation

$u_{1t}^i$  -disturbance term of household i at time t in base camp equation

$u_{2t}^i$  -disturbance term of household i at time t in satellite camp equation

L- likelihood function

$\delta$  -vector of scaling parameters for random effect terms

$\phi$  - standard normal p.d.f.

$\Phi$  - standard normal c.d.f.

$f_{bvn}$  -bivariate normal p.d.f.

$F_{bvn}$  -bivariate normal c.d.f.

## Endnotes

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<sup>1</sup> An alternative policy measure that has been suggested is privatization of rangelands [19]. However, individualization of tenure may in fact threaten tenure security in pastoral areas [31]. This is for reasons similar to those Platteau [30] identifies as inhibiting tenure policy from achieving efficiency gains in sub-Saharan Africa.

<sup>2</sup> Specifically, it is argued that areas with annual rainfall levels below 400 mm per year and coefficients of variation for rainfall greater than 30 [8] production conditions make it unlikely that animal populations are the fundamental cause of changes in rangeland productivity.

<sup>3</sup> Recent range ecology research focuses on stochastic herd loss as the mechanism limiting herders' ability to choose a stocking rate. The current study provides an alternative approach, as it specifies herd growth as a function of current period herd size and rangeland condition. This corresponds to the assumption that herders are credit constrained in their stocking decisions.

<sup>4</sup> The share can correspond to either herd splitting or intra-period migration.

<sup>5</sup> There are two rainy seasons per-year in northern Kenya. What is called the long rains occurs in March-May while the short rains occur in mid-September- mid-December. Two dry seasons of approximately three months length separate the rainy seasons.

<sup>6</sup> Base camps within one hour of town are defined as being in town (0 distance) as they effectively are using the rangelands of the town. While there is no upper limit imposed on how far a base camp can be from town, only 1% of base camps were reported to be located more than 24 hours from town. Most satellite camps are located more than 24 hours from town.

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<sup>7</sup> An additional laborer sent to satellite camp corresponds to a 19 TLU increase in herd size at satellite camp, which is used in the policy simulation presented below. In no case was the entire household labor force sent to the satellite camp.

<sup>8</sup> Given the retrospective nature of the data collection, this variable is unfortunately an *ex post* description of when a raid occurred rather than an *ex ante* description of when raids were anticipated. It is assumed the raids that occurred were anticipated.

<sup>9</sup> Food aid is distributed in equal quantities to all households registered as living in an administrative district.

<sup>10</sup> The evaluation scale was defined by 1= very low, 2= low, 3= average, 4= high, 5= very high.

<sup>11</sup> Representing pasture availability by *pa*, forage production by *fp*, and stocking pressure by *sp*, OLS analysis of these rankings for area one results in

$$pa_{1t} = .164 + .986fp_{1t} - .079sp_{1t} \quad R^2 = .77, \text{ and in area two}$$

$$pa_{2t} = .872 + .812fp_{1t} - .180sp_{1t} \quad R^2 = .71 \text{ with all coefficients significant at a 10\% level or}$$

better with heteroskedastic consistent standard errors. Area one was defined as rangelands within a 5 hour walk of town, area two as rangelands outside this area. Of particular interest in these results is that herders seem to recognize both that the area near town has lower mean pasture availability and that stocking decision of others negatively impact overall pasture availability.

<sup>12</sup> The household equivalent scale follows Martin [26]. Males and females older than 15 years old equal 1 household adult equivalent, ages 5-14 equal 0.6 household equivalent, ages 2-5 equal 0.3 household equivalent, and ages below 2 equal 0.1 household equivalent.

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<sup>13</sup> Herd size is measured in Tropical Livestock Units (TLUs), where 0.7 camel=1head of cattle=10 smallstock. This differs slightly from the weighting scheme reported in the Range Management Handbook[34], as this source suggests 11 goats = 10 sheep = 1 TLU. The data set records the combined smallstock herd size, so no distinction is made between sheep and goats.

<sup>14</sup> Fixed effect household characteristics include the average age of the household head, the average husband to wife age ratio, the average herd size in TLU, and the average household size in adult equivalents.

<sup>15</sup> This contrasts with the traditional migration strategy that had herders leaving lowland areas near permanent water sources during rainy seasons to use highland areas characterized by temporary water sources [32]. The towns of the study area have grown up around permanent water points in the lowlands over the past 30 years.

<sup>16</sup> Recent research in Marsabit District suggests this dietary preference serves a practical purpose. Nomadic children are found to suffer a lower incidence of malnutrition than do their counterparts settled in towns. Higher consumption of milk and less reliance on grains by nomads is proposed as the explanation for this pattern [13].

<sup>17</sup> Although the variable recording time periods when raids occurred did not significantly influence herder decisions, herders insist improving the public service of security is required to allow a more optimal distribution of grazing pressure. Many of the remote areas in the District have been effectively abandoned as grazing areas due to the threat of violent raids. As these threats are seen as ever-present, it may be that the true influence of raiding was not adequately represented by the variable used in the estimation methodology.