The effect of environmental variability on livestock and land-use management: The Borana plateau, southern Ethiopia

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Abstract

The Borana people are the predominant ethnic group on the Borana plateau in southern Ethiopia. Though traditionally transhumant pastoralists, they have recently increased their reliance on crops. Rainfall in the region averages between 353 and 873 mm; variability is high, with coefficients of variation ranging from 0.21 to 0.68. Anecdotal evidence implies that the vulnerability of pastoralist households to drought is increasing; stock levels increase dramatically during good rainfall years but plummet when rainfall is poor, indicating that the drought cycle is becoming more pronounced. In recent years, there has also been a dramatic increase in land allocated to crops, and land allocated to pastures that are either privatised or accessible to only a small subgroup of people. Nonetheless, the Borana are still highly dependent on access to common grazing lands, which provide the predominant source of forage and which also provide a mechanism to reduce risk of poor rainfall in one area by allowing for mobility. Because many of the land resources are used and managed in common, the authors hypothesise that one of the key determinants of the productivity and sustainability of the systems is the ability of community members to co-operate over the use and maintenance of these resources.

In this report, we develop indicators of co-operation and examine factors affecting these indicators. We then use these indicators to determine the impact of co-operation on stock densities and land allocation patterns. Results indicate that co-operation is positively related to factors that increase the profitability of livestock, but negatively related to the total number of households, the use of community pastures by non-community members, and heterogeneity of wealth within the community. Furthermore, stock densities are negatively related to the index of co-operation, as we would expect. Stock densities are also lower in areas with more highly variable rainfall indicating that high variability reduces the number of livestock held, contrary to the oft-mentioned hypothesis that households build greater stockholdings in areas where rainfall is highly variable to survive a drought with more animals. Finally, results from the land allocation estimations give evidence to support the notion that more land is privatised—either for crops or pasture—where levels of co-operation are lower. Given the importance of mobility and the poor suitability of most land for cropping, measures to offset the increasing densities and land privatisation should focus on improving the capacity of communities to co-operate and mitigate the impact of heterogeneity on that capacity, and on improving market access to improve co-operation and increase incentives to sell stock in good as well as poor rainfall years. Results also highlight the need to search for alternative policy mechanisms that mitigate the impact of drought, but that do not simultaneously increase incentives to increase herd levels in non-drought years.

1 Introduction

Many of the property rights systems governing access, use and management rights to natural resources in Africa originated as communal systems with households having exclusive rights to croplands and shared access to rangelands, forests and water resources. These systems served well especially during phases of low population pressure and little environmental degradation. With the advent of high population pressure, increased market activity and diminished authority of traditional leaders, a need to adapt these regimes to the increased pressure on the finite natural resource base has become a key policy concern (Bromley and Cernea 1989; North 1994; Pender et al. 1999). Some scholars view traditional African land tenure systems as inefficient and advocate for various modifications. Although empirical studies now challenge the validity of these assertions (Place and Hazell 1993; Ngaido 1995; Okoth-Ogendo 1995), the former view triggered tenure reforms in most parts of the continent over the past decades. Both socialist and market-oriented land reforms have not performed in terms of increasing productivity, particularly in the semi-arid regions where extensive and semi-extensive livestock production forms the basis of the household's production activities and income. Most of the reform codes were designed to replace existing community management systems with state ownership or models of private property. Broad claims by the state to 'pastoral' resources have led to a breakdown of traditional community management. At the same time, these measures have largely been unaccompanied by effective state management of those resources, and open-access situations have often resulted (Niamir-Fuller 1999).

Many attempts at 'privatisation' in these areas have been loosely based on the 'Western ranch model', where well-defined and rigid numbers of members were given title to a well-defined area of land. Though the Western ranch model itself was based on the assumption of private, individual property, these created ranches more closely resembled a common property resource with well-defined membership and a well-defined resource. In most cases, the ranch model failed because:

1. The ranch areas were not sufficiently large to support enough livestock units per family, given the high spatial and temporal variation in rainfall and forage.
2. In certain cases, large and powerful pastoralists became the *de facto* 'owners' of the ranch, effectively excluding large segments of the population, and capturing rents on the ranches while still using remaining non-ranch based common pastures. In these cases, the reforms certainly failed in terms of equity, and often in terms of efficiency as well (Swallow and Kamara 1999).

The reforms in Kenya after independence, in Ethiopia in the mid-1970s, and the *rural code* in Niger are some examples (Ngaido 1995; Okoth-Ogendo 1995; Zegeye Asfaw and Girma Tolossa 1997).

Oddly enough, at the same time that government and international donor projects promoting sedentarisation via the ranch model were failing, there were also instances of more spontaneous—or pastoralist-driven—sedentarisation, particularly in East Africa; a process which continues today. However, most of these changes were not entirely driven by internal forces. In many cases, they were precipitated by externally financed borehole or other water source development projects that raised the value of land around the water sources (Behnke 1988; Graham 1988; Ouedraoga 1996; Grell and Kirk 1999). Another major factor promoting increased sedentarisation and privatisation of at least some of the rangeland have been actual and/or perceived changes in formal legal framework for land titling and the likelihood of land reform by national governments. For instance, in Namibia, Devereux (1996) argued that large-scale pre-emptive fencing of rangeland since independence has been caused by increased population pressure and thus increasing scarcity of forage and water resources (exacerbated by the return of exiles after independence) and by the belief that land reform would favour those with ‘claims’ to land. In regions where fencing specifically for rangeland is not permitted —rangeland being ‘state land’ that is more or less managed by local elders and chiefs through the enforcement of traditional norms and rules—individual herders have instead registered claims to ‘cultivated’ land, as in Ethiopia (Graham 1988; Swallow and Kamara 1999). In these cases, rangeland is seen as under the control of local tribal leaders, but cropland can be individually appropriated by applying to the mandatory government authority. In many cases, land is then used as pasture. The bottom line is that, no matter what the driving force for initial phases of privatisation and fencing, once herders perceive that they may lose all claims to land if they themselves do not fence, the loss of common grazing land becomes self-fulfilling.

But privatisation is certainly not the only efficient development pathway, particularly not in the semi-arid areas where environmental risk is a driving factor in land use and livestock productivity (Behnke and Scoones 1993; Coppock 1994; Niamir-Fuller 1999). It has also been very forcefully argued by proponents of the ‘new range ecology’ that, particularly for semi-arid rangelands that exhibit a relatively high degree of variation, mobility and thus access to a relatively large number of rangeland ‘patches’ is required; such mobility is much more easily accommodated when rangelands are communal (c.f. Behnke and Scoones 1993; Niamir-Fuller 1999).[1] Nonetheless, how much land is privatised will be a function of the productivity of the land when it remains in common, as well as other external pressures. Thus, where communities can manage their rangeland resources,[2] common property will be the most efficient (and perhaps equitable) property rights structure and we should observe less privatisation, all else being equal. Private property will only become ‘optimal’ when management of the common rangeland is so poor that it becomes welfare increasing to individually appropriate land. In this case, the appropriator will be gaining higher mean returns per hectare, but a cost will be borne due to greater variability in production.

1. These environments are ususally termed non-equilibrial, or ‘at disequilibrium’. Semi-arid rangelands with a coefficient of variation of rainfall above approximately 0.3–0.33 are characterised as being non-equilibrial (Behnke and Scoones 1993; Scoones 1994).

2. We use the term ‘can manage’ to imply that external agents recognise their authority to manage and that the community itself is capable of implementing management decisions internally.

Given that sub-Saharan Africa hosts about 25 million of the world’s pastoral population deriving their livelihood directly from communal land use (Swallow 1994), there is a need to assess the major forces driving these changes so that their relevance to policy formulation can be evaluated. This study is intended to enhance understanding of these processes of change in eastern Africa, using the Borana rangelands of southern Ethiopia as a case study. These semi-arid southern rangelands support the livestock that are highly valuable to Ethiopia as sources of direct consumption and income of the Borana people, for the provision of draft power for smallholders in the highlands, and for export to generate foreign exchange. Despite the consensus on the region’s high ecological potential for livestock production, the area is seen as one that is still in crisis today, mostly due to pressure on the common rangelands, high population growth rates, and increased privatisation for both cultivation and grazing. In some areas stocking rates are high, whereas the actual stocking rates in other areas fall below the potential carrying capacities. This trend is attributed to a series of factors, among which changes in property institutions is frequently cited (Coppock 1994; Kerven and Cox 1996; Hogg 1997).

Against this background, we undertake this study as an attempt to answer, with empirical evidence, some of the questions arising from current theoretical discussions on stock levels, rangeland degradation and the commons. Theoretical considerations revolve around the theories of agricultural intensification and induced innovation, viewed from the perspective of collective action and institutional change (Boserup 1981; Binswanger and McIntire 1987; Lele and Stone 1989; Ostrom 1990). Proponents of these theories assert that population pressure, changes in market conditions and technology may induce changes at the local level as a result of changing factor scarcities and prices. Local level responses to these changes may depend on the available institutions facilitating the process, and on baseline community characteristics such as endowments of natural resources, infrastructure, and the stock of social capital. Based on these constraining factors, a divergence in preferences for property regimes may result, leading to different pathways of livestock intensification, land use patterns and quality of the natural resource base (Lele and Stone 1989; McIntire et al. 1992; North 1994; Pender et al. 1999).

2 Methodology and data collection

[2.1 Study area]

[2.2 Sample selection and stratification]

[2.3 Stages of the data collection]

[2.4 Descriptive statistics]

[2.4.1 Socio-economic characteristics of the sample communities]

[2.4.2 Current land use patterns and property rights]

A field survey was conducted in 40 rural communities in the 6 districts of the Borana rangelands from September 1997 to July 1998. The choice of the community as a unit of study is based on the fact that the spatial and temporal use of key production resources in the area is communal, and access is largely determined by community level decisions—mostly by elders who define rules and ensure the implementation of sanctions and penalties. It therefore becomes expedient to look beyond the household for an analytical unit that corresponds to the level at which decisions about resource use and property rights are made. A community in this study consists of two or more pastoral settlements having common access to pastures and water resources to which they bear a common claim, called an *arda.*

2.1 Study area

The Borana rangelands are found at the south-most part of the Ethiopian lowlands occupying a total land area of about 95 thousand square kilometres. They are located at 4–6°N and 36–42°E sloping gently from 1600 metre above sea level (masl) in the north-east to about 1000 masl in the extreme south that borders northern Kenya. The area is still predominantly in pastures comprised of flat plains forming the main parts of the range. There are occasional mountains, massive valleys and depressions. Occupied almost entirely by pastoral populations, resource use on the Borana rangelands is largely communal, though with crop cultivation and private enclosures that appear to be increasing in recent decades. The area exhibits a bimodal pattern of precipitation, with the long rains falling between March and May, and the short rains between September and November. Spatial and temporal variability in both the quantity and distribution of rainfall renders the area semi-arid, with an average annual rainfall varying from 353 to 873 mm per annum.

2.2 Sample selection and stratification

The communities were selected to represent different rainfall patterns (level and variation) and access to markets. Data on 14 years of monthly rainfall (1982–96) from 12 weather stations located across the area were used to classify the communities into 4 different rainfall categories: high mean with high variation; high mean with low variation; low mean with high variation; and low mean with low variation. The weather stations also varied in terms of access to markets. The easy access category corresponds to those located within 25 km average distance from major markets, while those located farther than 25 km are categorised as difficult access.[3] Three to five communities were randomly selected from around each station to cover the various rainfall categories and different degrees of market access.

3. The criteria are based on the fact that Borana pastoralists trek a maximum distance of about 20 to 25 km a day. Locations beyond these distances are associated with high marketing costs both in terms of time and financial resources. Since there is no transport of cattle in trucks until you reach the major market centres on the paved roads, trekking time and distance should represent the same in terms of transportation costs.

2.3 Stages of the data collection

The first phase of the data collection used a combination of standard questionnaires and rapid rural appraisal techniques. The respondents included community elders, heads of encampments or other key informants, responding as a group. Social mapping was used to assess the proportion of land under different types of land uses—different types of common property grazing areas, transhumance routes, cultivated area, private enclosures etc. This was followed by rapid rural appraisals on wealth ranking and a closed-ended questionnaire capturing total livestock holdings, proportion of members engaged in nonfarm income generating activities, rules and regulations over the various resources, and basic information on demographics and infrastructure. This was followed by a physical identification of boundaries of the *arda*. A GPS (global positioning system) instrument was used to obtain co-ordinates of community border points, which were later digitised and analysed to generate community maps and land areas. Range quality data were also generated from each of the communities with the help of a range specialist.

2.4 Descriptive statistics

In this section, we present some descriptive statistics from the study area.

2.4.1 Socio-economic characteristics of the sample communities

The communities consist of a total of about 200 settlements or pastoral encampments, with an average of 5 settlements per community. These constitute a total of 3141 households, with an average of 79 households per community, and 7 people per household. The total human population of all the communities is 21,637 people, with a mean of 541 people per community. About 26% of the households are female headed. The majority (67%) of the households are classified as poor, about 21% as middle class and only 12% as wealthy.[4]

4. This is based on the wealth stratification criteria suggested by the respective communities according to their definitions and perceptions of wealth.

Cattle are by far the most important livestock species held by the Borana pastoralists and account for about 90% of the total livestock holdings in the area. This amounts to about 50 thousand tropical livestock units (TLU) or 64.4 thousand head. The remaining 10% consists of small ruminants, camels and equines. The mean number of livestock per community is 1249 TLU, with a minimum of 82 and a maximum of 5900 TLU. The average livestock holding at the household level varies between 2 TLU for poorer households and to above 100 TLU for wealthier ones, with an aggregate mean of 17 TLU.

2.4.2 Current land use patterns and property rights

In this study, land use is aggregated into crop and livestock production, and property rights into private and common. About 84% of the total land area is allocated to livestock production activities while 16% is currently under crops (Figure 1). The land area under livestock is largely managed as different forms of common property (76%) denoted by (c) in Figure 1.

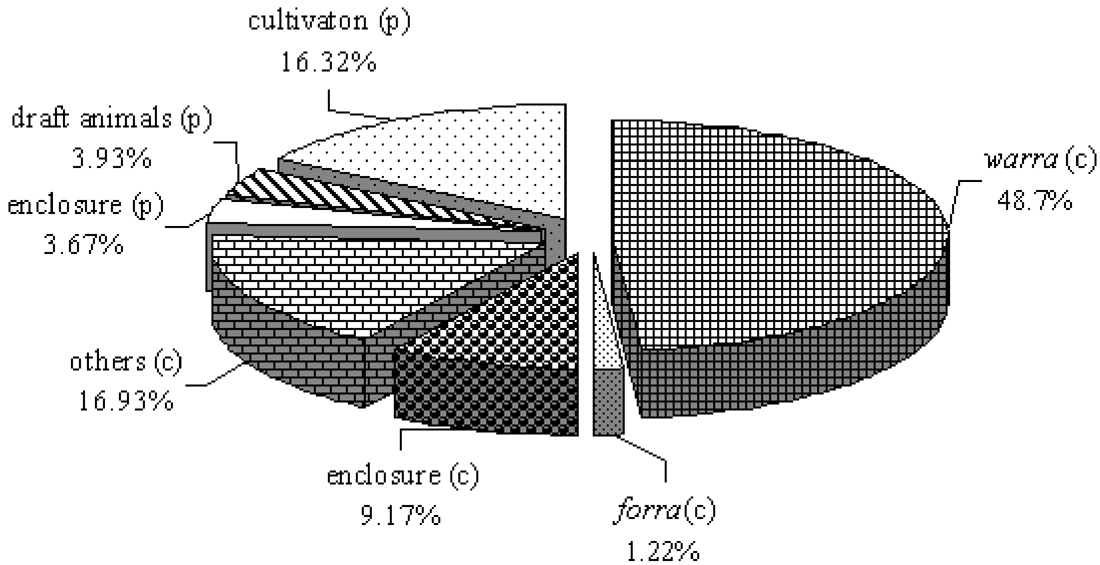

Figure 1. *Land use patterns and property regimes in percent of land area (c = common; p = private regime).*

Warra grazing is by far the most predominant form of common property in the area constituting about 48.7% of the total land area. These are communal grazing areas for milking cows, calves and sick or weak animals during the year, and are often used by dry herds during the rainy seasons. They are accessible to all members of a defined community at specified periods of the year and for specified types of animals, but may be used by outsiders during some times of the year with permission. In this context, *warra* areas largely fit the definition of regulated common property resources. Communal en- closures for calves and sick or weak animals account for 9.17% of the total land area; these enclosures can pertain either to the entire community, or in many cases, to only a subset of households in one encampment. Unlike *warra* areas, they are rarely open to non-*arda* members.

Community level enclosures and *warra* areas are present in about 83% of the sample communities and hence constitute the most important forms of common property resources. *Forra* areas are unrestricted communal grazing areas for dry herds—non-lactating livestock—for all members of the Borana pastoral ethnic group. Spatial and temporal access to such areas is unregulated at all times. *Forra* areas generally constitute the largest communal grazing areas in Borana but being unsettled, they largely fall outside the boundaries of the communities under investigation, and thus comprise only about 1.22% of the total land area.[5] Areas around settlements are used for grazing small ruminants, camels and equines. Private holdings account for about 23% of the total land area, allocated mainly to crop production (16.32%), partly to enclosed private grazing (3.67%), and partly to enclosed areas for draft animal grazing around cultivated fields (3.93%). Private enclosures for grazing are a relatively new phenomenon that alludes to a new dimension in the dynamics of property rights in the area. Such trends were observed in 17.5% of the communities under investigation.

5. Our population densities are much higher than those previously reported. This is because we took the land area for a particular community to be only that falling within the *arda* boundaries. Densities over the entire plateau are lower, because of the larger *forra* areas to which all Boranas have access.

Appendix I contains a table of descriptive statistics for a number of variables, with communities assigned to four groups: high rainfall, low coefficient of variation (CV); high rainfall, high CV; low rainfall, low CV; and low rainfall, high CV.

3 Model development

3.1 Basic model

3.2 Rainfall variability

3.3 Co-operation at the community level

3.1 Basic model

In this section, we develop a model of stock densities and land allocation at the community level. The model is developed in stages; first we present equations based on a theoretical model of optimal stock densities and land allocation in the absence of rainfall variability, and based on the assumption that community members are not co-operating. Next, we consider the theoretical effect of risk—in terms of rainfall variability—to the empirical model. Finally, we consider the effect that co-operation may have on community level decisions. Because there were no formal rules on stock densities in any of the communities, we do not directly observe a co-operative level reached by the community (which would itself define the stock densities). Though our ultimate goal is to develop a proxy for the level of co-operation reached in each community, we are also concerned with factors which themselves determine the level of co-operation, and we digress to consider these variables in section 3.3.

To begin, we posit the following equations:

$$SD = f(P_i/P_g,\ MktDist,\ RangeCondition,\ TotalHH,\ Hay)$$
$$\%L_{crops} = f(P_i/P_g,\ MktDist,\ Range,\ SD,\ TotalHH)$$
$$\%L_{pvtpast} = f(SD,\ TotalHH)$$

These equations are easily obtained from a non-co-operative game, where community members choose stock densities (SD) and land allocated to crops ($\%L_{crops}$) and to private pastures ($\%L_{pvtpast}$) (c.f. McCarthy et al. 1998). Stock density determines the marginal product of land in common pastures, and is thus an explanatory variable in the land allocation equations. In this model, the decisions on stock densities and land allocation are recursive. A sufficient condition for recursivity is that livestock production can be characterised as a quadratic function of stock densities—a specification that has a great deal of empirical support (Hart et al. 1989; Seligman et al. 1989). Alternatively, we might think of the decision as sequential; in the first stage land allocation decisions are made, and in the second stage, given land allocated to pastures, members choose how many animals will be stocked per hectare. Using backwards induction, we first calculate the stock densities that will arise from non-co-operative use of the rangeland and the resulting marginal product of land in pasture, and then calculate optimal land allocation based on this stock density.

Stocking densities are hypothesised to be a positive function of range condition and of the relative price of livestock to crops $[P_i / P_c]$, and a negative function of the distance to the nearest major markets (*MktDist*).[6] Data for the range condition score were collected by a range specialist from the International Livestock Research Institute (ILRI); the score is based on such measures as dry matter and crude protein content along transects within an *arda*, slope measurements and the area covered by bush and barren land. Total households (*TotalHH*) capture the extent of 'overgrazing' since—in the absence of adoption of productivity enhancing technologies—the total stock density at the community level should be independent of the total number of members.[7] We observed very little adoption of productivity-enhancing technologies; use of purchased feeds was rare, crop residues were left in the fields, and grazing on these areas was for very short periods of time. However, staff members at the Yabello-based CARE office have promoted hay-making technologies; we thus include a dummy variable for haymaking at the community level *(Hay)*.

6. Respondents of the community-level surveys were asked to identify the major markets for livestock and crops. Enumerators then calculated the distance to these markets. Enumerators collected separate price data in the markets identified; therefore the prices used in the analysis are those from the markets, and are not arda or farm-gate prices.

7. If the underlying production function is constant returns to scale, as we implicitly assume, then stock densities will be a function of the total number of households, and not to household density.

The percent of land allocated to crops is hypothesised to be positively related to rainfall *(Rain),* and negatively related to the relative price of livestock/grain and the distance to market. Because higher stock densities cause the marginal product of land in common pastures to be lower, we expect a greater allocation of land to crops; the higher is the stock density. Also, total households will have an additional positive affect on land allocated to crops. This is because land allocated to common pastures is akin to the provision of a public good; under non-co-operation, we expect that less of the public good will be provided the greater is the number of members (c.f. McCarthy et al. 1998).

In the simple model developed thus far, the only reason to allocate land to private pastures is the extent of non-co-operation on the common grazing land, here captured by stock densities and total households.

3.2 Rainfall variability

Next, we considered output variability caused by erratic rainfall. If we assume that the pastoralists are risk-averse livestock producers, then stock densities will be lower the higher is rainfall variability (Sandler and Sterbenz 1990; McCarthy 1999). Thus, we hypothesise that higher variability will lead to lower stocking densities and that these lower stock densities will in turn increase the marginal product of land in common pastures. As before, lower stock densities will lead to greater marginal product of land, and as before, we expect lower stock densities to lead to lower allocations of land to crops and to private pasture. However, it is difficult to predict the direct effect of rainfall variability on land allocation in the absence of specific information on the variance of crops, livestock outputs, and the co-variance between these activities. Land in the study area is fairly marginal land (except key points) and rainfall is characterised by a bi-modal distribution leading to very short growing seasons. Under these conditions, it is likely that crop output is more variable than livestock output, since livestock production is more mobile and flexible. Even so, greater relative variability of crops vs. livestock is not sufficient to sign the direct impact of rainfall variability.[8] The theoretical sign of this variable is ambiguous, though under plausible assumptions on variability and co-variance across activities, we expect that land allocated to crops will be a negative function of rainfall variability.

8. The problem of signing the response in a multi-output stochastic framework is made more complicated by the fact that cropping is undertaken on ‘private’ land and that livestock are kept on common land. Given additional ‘risk’ externalities when use of the common lands is characterised by non-co-operative behaviour, results that are standard under the complete private rights case no longer hold.

Furthermore, it has been hypothesised by a number of researchers of semi-arid rangelands in sub-Saharan Africa that areas with coefficients of variation greater than 0.33 will exhibit a different composition of forage species and that these systems will exhibit 'non- equilibrium' behaviour, by which is meant that forage productivity is primarily dictated by rainfall, and that stocking densities will have a very low or insignificant impact on forage productivity as long as livestock are still mobile throughout the year (Ellis et al. 1993; Scoones 1995; Niamir-Fuller 1999). This distinction now forms the basis of what is called the 'new range ecology'. Researchers supporting this distinction—largely range ecologists—have gone on to hypothesise that in these environments producers will try and build up large numbers of animals in more highly variable environments because a) stock densities will not affect future forage productivity and b) it is a 'better strategy'[9] to hold more animals in anticipation of a very poor rainfall—the more you go in with, the more you come out with. As noted above, we undertook our surveys in a year that followed six years of relatively average to good rainfall and we expect to be on the 'up side' in a drought cycle. In the model developed below, we can test these two competing hypotheses by allowing the slope and intercept to change for communities with coefficients of variation above and below 0.33.

9. The fact that this may be a best-response individual strategy under private pastures, but not a 'better strategy' if in fact followed by all community members, is not much addressed in the literature. To highlight the confusion in the literature, consider the following: Behnke and Scoones (1993, 15) wrote 'Ellis and his colleagues found that in central Turkana, rainfall levels affected all aspects of the production system… Livestock losses due to drought could cut herd sizes in half, but there was little evidence that rates of loss were closely related to stocking rates.' But, here is what Ellis et al. (1993, vi) actually reported: 'The results of this study suggest that several characteristics of Turkana pastoral systems are related directly to drought resistance and inversely to famine susceptibility… low to moderate stocking rates.' Communities with lower stocking densities relative to their regional 'carrying capacities' 'fared better… in terms of lower overall livestock mortality, more rapid recovery of livestock herds after the drought and greater continuity of an adequate food supply from pastoral products' (Ellis et al. 1993, 193).

3.3 Co-operation at the community level

Finally, we consider what happens when communities attempt to manage their common pastures. While no community had explicit rules on the number of livestock that could be held by each household, informal discussions revealed that members believed that there could be negative effects on each individual's productivity if there are too many animals on the pastures for too many months of the year. We thus hypothesise that implicit informal 'rules' or norms may in fact operate to reduce stocking pressure.

The literature on factors associated with successful management of common pool resources is vast.[10] Many of these factors can be thought of as shift variables in a cost function for undertaking various collective action activities—including the management of common pool resources—and may be thought of as social capital. Put differently, these factors should lower costs for any activity the group chooses to undertake, and are distinct from the underlying technical characteristics of those separate activities (Dutilly- Diane 2001). Nonetheless, measures of 'social capital' are difficult to capture in many field situations.[11] The densities of various networks are one of the main components of many social capital studies; but our data were collected at the community level and as such only picked up information on relevant community-level institutions, specifically those in charge of resource management. Our ultimate goal is to develop an indicator of the level of co-operation reached in other activities, and to relate this measurement to observed stock densities and land use patterns, which is somewhat different than capturing 'social capital' per se. We thus construct indicators of (non-)

co-operation based on observable features of resource management institutions' structure and function, such as the number of meetings held per year, per cent of members attending, number of different types of rules over the various natural resources, and violations occurring in the last five years. In particular, the number of rules and violations are themselves a function of social capital. We hypothesise that success in creating and enforcing rules in activities other than stock densities will adequately capture the underlying social capital within each community. To test whether or not indicators in fact capture degrees of co-operation or non-co-operation, we specify the following:

$$I\text{-}NC = f\begin{pmatrix} TotalHH, Hetrogeneity, OutsidersIn, MembersOut, \\ OutsideWageWork, P_l/P_c, MktDist, RainVar \end{pmatrix}$$

10. Bromley and Cernea (1989), Ostrom (1990) and Berkes and Folke (1998) are a few volumes containing empirical examples.

11.The World Bank has produced a number of documents useful for operationalising the concept of social capital, including a working paper series from the Local Level Institutions Study which are available from Social Development Family, Environmentally and Socially Sustainable Development Network and the Environmentally and Socially Sustainable Development Division and the papers prepared for the Social Capital Initiative (www.worldbank.org/poverty/scapital/scindex.htm)

The index of non-co-operation (I-NC) is hypothesised to be a positive function of the total number of households since the greater the number of households, the higher are the individual incentives not to abide by agreements, and the more difficult it is to reach consensus and enforce decisions. Greater heterogeneity in wealth *(Heterogeneity)* is hypothesised to lead to differences in levels of risk aversion, and the greater are these differences, the more difficult it will be for members to find agreements that leave all members better off.[12] The index is also hypothesised to be a positive function of whether or not outsiders regularly come into the *arda* (*OutsidersIn*) since benefits from reduced stocking pressure will then accrue to non-members. Members engaging in seasonal migration outside the community *(MembersOut)* may represent less pressure on the resources; this is one mechanism to reduce grazing pressure, but it may also make it more difficult to make and enforce rules, thus the sign of this variable is ambiguous. Outside wage work is hypothesised to be associated with greater opportunity costs of community participation, and to lead to a higher index of non-co-operation. Favourable relative livestock prices, shorter distances to markets, and range quality are hypothesised to be negatively related to non-co-operation. Though individual incentives to co-operate and not co-operate increase with variables that increase profitability, the overall effect is in favour of greater co-operation (c.f. McCarthy et al. 2001). Finally, rainfall variability *(RainVar)* is hypothesised to negatively affect non-co-operation—the greater the variability the greater are the gains to co-operation vis-à-vis the gains from cheating (McCarthy 1999).

12. In the case of regulating use-rates on a common pool resource exhibiting both non-exclusion (of members) and subtractibility in use, we posit that the effect of heterogeneity in wealth on co-operation will always be non-positive. This is in contrast with recent debates in the literature on the role of heterogeneity, where oftentimes the objective of co-operation is more akin to providing a public good (non-subtractibility in use), where heterogeneity in wealth may in fact have a positive effect on provision of a public good.

Incorporating environmental variability and the index of non-co-operation into the stock density and land allocation model leads to the following equations:

$$SD = f(P_l/Pc, MktDist, RangeCondition, TotalHH, I\text{-}NC, Rain\ Var)$$
$$\%L_{crops} = f(Pl/Pc, MktDist, TotalHH, I\text{-}NC, RainVar)$$

$\%L_{pvtpast} = f(SD, TotalHH, I\text{-}NC, RainVar)$

4 Data analysis

4.1 Factor analysis

4.2 Stocking rate equation

4.3 Land allocation equations

4.1 Factor analysis

To develop indicators of co-operation/non-co-operation, we perform a factor analysis on those variables thought to represent the extent of co-operation reached. We included number of meetings per year as well as the percentage of the community members attending; the sum of rules pertaining to pasture and water point use and maintenance; the sum of rules pertaining to grazing, water, settlement and cultivation; and the number of violations of these rules occurring in the last five years.[13] Grazing rules often referred to restrictions on types of animals using various parts of the range, seasonal restrictions on access, and use of calf and draft animal enclosures. Water rules were largely comprised of maintenance activities and seasonal restrictions. Settlement and cultivation rules mainly consisted of obeying 'zoning' restrictions and fence maintenance. Because we are interested in the structure of the co-operation 'model', we use factor analysis. Using STATA software,[14] we performed a Principal Components factor analysis and obtained factor loadings and scoring coefficients from rotated factors using the varimax option. Four components had eigenvalues greater than 1; factor loadings are presented in Table 1 below.

13. We restricted violations per rule to these rules, as there were many instances where there were no rules on either settlement or cultivation.

14. All calculations were performed using STATA, unless otherwise indicated

Table 1. *Results of factor analysis—Factor loadings.*

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Number of meetings per year	0.029	0.706	0.24	0.048
Members attending (%)	0.404	–0.324	–0.224	0.531
Sum grazing rules	0.06	–0.014	0.835	0.17
Sum water rules	–0.014	0.374	–0.578	0.49
Sum settlement and cultivation rules	0.229	0.082	–0.206	–0.812
Violations: Grazing rules	0.913	0.154	0.181	–0.079
Violations: Water rules	0.114	0.841	–0.224	–0.132
Violations: Settlement and cultivation rules	0.692	–0.094	–0.429	–0.106

As can be easily seen, none of the factors is readily interpreted and the fact that four factors are retained out of seven variables indicates that correlation among the variables is not extraordinarily high. The first factor has relatively low but positive loadings on variables thought to positively affect co-operation, but also high loadings on violations. The second factor has high loadings on meetings and water rules, but a strong negative loading on per cent of members attending. It also has a very strong loading on water violations, but a negative loading on settlement and cultivation rules, and a relatively low loading on grazing violations. The third and fourth factors are equally difficult to interpret. We proceed by obtaining the factors scores for only the first two factors (Table 2).

Table 2. *Results of factor analysis—Scoring coefficients.*

Variables	Factor 1	Factor 2
Number of meetings per year	0.035	0.498
Members attending (%)	0.288	–0.202
Sum grazing rules	0.14	0.048
Sum water rules	–0.044	0.26
Sum settlement and cultivation rules	0.074	–0.020
Violations: Grazing rules	0.622	0.092
Violations: Water rules	0.028	0.56
Violations: Settlement and cultivation rules	0.412	–0.110

Following the loadings, the first factor has a low loadings number of meetings, percentage attendance and rules. It also has very high and positive loadings on the rule violation variables, particularly grazing and settlement and cultivation rules. We thus hypothesise that this factor captures non-co-operation. The second factor is quite mixed. In terms of violations, here water violations have a strong scoring coefficient, but grazing rules and settlement and cultivations rules are low or negative. In contrast to factor 1, the second factor has a high coefficient on meetings, but a negative coefficient on percentage attending. Given the contrast with the first factor, then, we hypothesise that this factor captures degree of co-operation—notwithstanding the high loadings on both water rules and violations.

We then regressed the indices on factors hypothesised to affect co-operation. Total households and the square of households were used to test the hypothesis that co-operation is more difficult both with relatively few households (because of fixed costs) and with many households (because of higher communications costs). Higher relative prices, higher range quality, and shorter distance to markets are hypothesised to increase co-operative levels, since gains to co-operating should be greater than gains to not co-operating as prices and range quality increase and distance falls. Co-operation should also be greater where the CV in rainfall is greater, since gains to co-operating should increase relative to gains from not co-operating the higher the variability in rainfall (McCarthy 1999); we also allow for a non-linear affect of rainfall variability by adding a squared term. A dummy variable indicating whether community members migrated to outside pastures for at least 1 month during the preceding year and a variable capturing the number of months outsiders used community pastures were included; both are expected to decrease co-operation, the first because benefits will not accrue to community members alone, and the second because communication may be more difficult when people are more mobile. The percentage of members engaged in outside wage work is hypothesised to capture the opportunity cost of dedicating time to community activities. Heterogeneity is measured by the CV in livestock holdings for the wealthy, moderate, and poor wealth classes, as determined by the communities. A Gini coefficient was also generated, but this measure of distribution did not perform as well as the simpler measure of distance. If smaller members do not form coalitions, then finding agreements mutually beneficial to all will in fact be a function of the distance between the 'biggest' and 'smallest', and not a function of the distribution per se. Heterogeneity is hypothesised to negatively affect co-operation due to fewer agreements mutually beneficial to all. Results are presented in Table 3.[15]

15. All estimations were performed using STATA 6.0; all used the cluster option to account for the clustering of communities around rainfall stations.

Table 3. *Regression results—Co-operation indices.*

	NonCoop		Coop	
Dependent variable	Coefficient	t-stat	Coefficient	t-stat
Total households	0.02*	1.96	0.02*	1.97
Total households2	–0.00007*	–2.04	–0.00006*	–1.79
CV of rainfall	–0.34	–0.04	10.53*	1.74
CV of rainfall2	–0.75	–0.07	–16.73**	–2.21
Relative livestock price	–1.24*	–1.81	1.85*	0.19

Distance to market	0.01	1.08	0.004	0.61
Range quality index	–0.20	–1.64	–0.04	–0.41
In-migration of animals	1.05*	1.91	0.52	1
Dummy for community animals out-migrating	–1.57**	–2.53	–0.72	–1.22
Per cent of members engaged in wage work	0.009**	2.24	–0.00001	–0.025
Heterogeneity in wealth	0.33**	2.97	–0.09	–1.47
Constant	0.11	0.05	–3.34	–2.03
Adjusted R2	0.53		0.46	
Sample size	39		39	
CV = coefficient of variation; * = significant at the 10% level; ** = significant at the 5% level.				

The NonCoop variable indeed seems to capture non-co-operation. However, non-co-operation is at first increasing and then decreasing in total households—contrary to the fixed cost/increasing variable cost hypothesis. The total impact is always positive in survey communities, but begins to decline at 285 households; in our sample just 1 community is larger than 285. High prices lead to lower non-co-operation, though distances to market do not have any statistically significant effect. Range quality is also negative, but not quite significant at the 10% level. In-migration positively affects NonCoop, which gives support to the hypothesis that use of core community grazing resources by others reduces incentives for community members themselves to co-operate. At the same time, when community members use outside pastures, non-co-operation is reduced. Instead of capturing additional costs of monitoring and enforcing agreements within the community when members are absent, out-migration may relieve stocking pressure on community grazing and water resources thereby contributing to easier management of those resources. The higher the percentage of members engaged in outside wage work and the greater the degree of heterogeneity in wealth, the higher is NonCoop, as hypothesised. Coefficient of variation in rainfall, however, has no effect. Overall, this regression has good explanatory power and results coincide with the main hypothesis regarding factors influencing the degree of non-co-operation.

The Coop variable also appears to capture co-operation, though results are more difficult to interpret than for the NonCoop variable. Households and households squared have the same effect—and almost the same coefficients—as for the NonCoop variable; though this is in accordance with the fixed/variable cost model, the impact of number of households is always positive in this sample, contrary to expectations. However, the higher the relative variability in rainfall, the greater is co-operation, though this too decreases at higher coefficients of variation; nonetheless, the effect is always positive for sample communities. Prices favouring the activity dependent on common pool resources (livestock versus grains, which rely on pastures and water resources) also positively affect this index of co-operation. Unlike the NonCoop variable, mobility by either insiders or outsiders has no significant impact, nor does the degree of heterogeneity.

4.2 Stocking rate equation

Because the indicators developed above are not without certain difficulties in interpretation, we present two specifications for the stocking rate equations—the first with the indices and the second with the explanatory variables themselves. We use a log-linear specification for stock densities, where fixed 'input' variables and prices are in log form (total households, relative livestock prices and distances to market), but shift variables are in levels (the co-operation indices, range quality, haymaking dummy, in-migration, dummy for out migration, per cent members engaged in wage work and the heterogeneity variable). The index variables, NonCoop and Coop, have also been normalised to lie in the 0–1 interval, to facilitate interpretation of results. As with the index equations, the stocking rate equations were also corrected for heteroskedasticity. (Results are presented in Table 4.)

Table 4. *Regression results–Stock densities.*

Dependent variable	Stock density Coefficient	t-stat	Stock density Coefficient	t-stat
Total households	0.60**	5.44	0.66**	5.67
(in natural logs)				
Haymaking	0.43	1.13	–0.29	–1.16
CV of rainfall	1.53	1.78	2.01*	1.87
(in natural logs)				
Dummy for high CV	–3.39**	–2.65	–3.11**	–2.68
Dummy* CV	–3.34**	–3.34	–2.96**	–3.18
Relative price of livestock/grain	1.19*	2.17	1.04*	1.91
(in natural logs)				
Distance to market	–0.09	–0.51	–0.17	–1.30
(in natural logs)				
Range quality index	0.09	1.68	0.04	0.43
NonCoop (normalised)	0.82**	2.3		
Coop (normalised)	–0.89	1.68		
In-migration of animals			0.15**	3.15
Dummy for community animals out-migrating			0.16	0.43
Per cent of members engaged in wage work			–0.004	–0.60
Heterogeneity in wealth			0.23**	2.42
Constant	–0.47	–0.35	–3.34	–2.03
Adjusted R^2	0.65		0.64	
Sample size	39		39	
CV = coefficient of variation; * = significant at the 10% level; ** = significant at the 5% level.				

In the first specification, the total number of households, relative livestock prices and the NonCoop variable all positively affect stocking densities as predicted; range quality and the CV in rainfall variables also have a positive effect but are not quite statistically significant. Coop is negative, but is also not quite significant at the 10% level. Neither the haymaking dummy nor distance to market had any significant impact on stock densities. The coefficient times the dummy for highly variable areas has a negative and significant effect, as does the dummy variable itself, thereby lending support to the hypothesis that it is precisely in the relatively high variability environments where lower livestock densities are observed, and not higher densities as has been suggested. However, it may be the case that high variability environments are less densely populated, so that animals per household can increase in response to the higher variability, without necessarily leading to higher stock densities *per se*. To check this hypothesis we can estimate stock levels instead of stock densities, and include the fixed factor of pastureland as an explanatory variable. These equations perform similarly to those presented above, the slope and intercept effects at relatively high coefficients of variation remain negative and significant. (Results are found in Appendix 2.)

The second specification performs similarly to the first; the adjusted R2 are almost the same at 0.65 and 0.64, respectively. Though the haymaking variable changes signs, all other coefficients remain of the same sign. Variables such as total households, prices, range quality, distance, and coefficient of variation (CV) in rainfall are expected to pick up both a direct effect as in the first specification, but also an indirect effect via co-operation. The coefficient on households increases *vis-à-vis* the first specification—capturing the additional effect from lowering co-operation and the coefficient on prices and range quality capturing the additional positive effect (Table 4). Distance also becomes more negative, as we would expect, but this variable is not significant in either specification. Finally, of the variables hypothesised to directly affect co-operation, we see that the heavier is use of home pastures by outsiders and the greater the heterogeneity within the community, the higher are stock levels; out-migration and wage work have no statistically significant effect.

4.3 Land allocation equations

The dependent variables for the land allocation equations are given in percentage (times 100) terms; there are 6 zero observations for land allocated to crops, and 3 zeros for land in private pastures. Although we cannot use logs for the dependent variables, the specification for the explanatory variables remains similar to the stock density equations. In addition to the variables discussed above —total households, relative livestock, grain prices, distance to market, rainfall, rainfall variability and the co-operation indices—in the cultivation equation we add the number of years a community has been cultivating. As noted in the introduction, the Boranas are historically livestock keepers, with more limited historical experience with cropping. Other authors have argued that cropping used to be undertaken sporadically to capture benefits during very good rainfall years, or alternatively, was undertaken by those who had lost their herds and was seen as a stop-gap measure undertaken only until the family could reconstruct their herds (Swallow and Kamara 1999). In the past 20 years or so, however, anecdotal evidence seems to support a more permanent shift into cropping; in these cases learning by observation and by doing will be important explanatory variables in understanding land allocation decisions. We lack data more appropriate to test spillover learning effects, and instead include the years cropping has been undertaken to proxy these effects. A SUR model was used. (Results are presented in Table 5.)

Table 5. *Regression results—Land allocation.*

	Percent of land in crops		Percent of land in private pasture		Percent of land in crops		Percent of land in private pasture	
	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Total households (in natural logs)	2.5	0.67	3.07	1.56	0.1	0.025	5.21	0.98
Average rainfall (in natural logs)	10.53	1.37	–9.48	–0.98	3.98	0.44	–2.03	–0.18
CV of rainfall (in natural logs)	9.28	1.56	4.92	0.62	9.11	1.16	–0.32	–0.03
Relative price of livestock (in natural logs)	19.23	1.59			17.52	1.53		
Distance to market (in natural logs)	–2.51	–0.99			–2.61	–1.04		
Years cultivating	0.45**	2.63			0.47**	2.74		
Stock densities (est.)	–0.50	–0.09	–9.81*	–1.72	1.21	0.26	–10.97*	–1.77
NonCoop (normalised)	–0.70	–0.08	17.37	1.55				
Coop (normalised)	–11.94	–1.53	9.81	0.99				
In-migration of animals					–0.76	–0.7	1.31	0.88
Dummy for community animals out-migrating					5.53	1	–13.56*	–1.83
Members engaged in wage work (%)					0.06	0.83	0.001	0.01
Heterogeneity in wealth					0.31	0.22	1.5	0.86
Constant	–39.54	–0.84	57.56	1.02	0.87	0.02	0.87	0.02
Adjusted R^2	0.54		0.16		0.55		0.18	
Sample size	39		39		39		39	
CV = coefficient of variation; * = significant at the 10% level; ** significant at the 5% level.								

Though the computed R^2 statistic is above 0.5 for both equations, only one individual coefficient (years cultivating) is statistically significant. For the land allocated to private pastures, the computed R is quite small, and the only significant coefficient is stock densities. Further, we hypothesised that the sign of this variable would be positive—higher densities would reduce the marginal product of land in common pastures and should thus lead to more land allocated to private pastures. The co-operation indices have no statistically significant effect in either equation. When we substitute the exogenous factors hypothesised to affect co-operation directly into the estimations in the last two specifications, we see that the dummy for whether community members routinely migrate out of the community for at least one month per year is the only statistically significant coefficient in the land allocated to private pastures equation. Coinciding with the impact on stock densities, this variable captures reduced pressure on home grazing areas, and thus fewer benefits to privatisation.

In our sample there are three communities with land allocation to private pastures and cropland exceeding 75% of the total land area. In one community, this reaches 94%. In Table 6, we re-estimate the equations dropping these three observations.

Table 6. *Regression results—Land allocation, reduced sample.*

	Percent of land in crops		Percent of land in pasture		Percent of land in crops		Percent of land in pasture	
	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Total households (in natural logs)	2.02	0.52	3.81	1.48	–0.22	–0.05	4.57*	1.64
Average rainfall (in natural logs)	10.21	1.29	–18.18**	–3.57	2.89	0.3	–18.95**	–3.09
CV of rainfall (in natural logs)	9.73	1.6	6.99*	1.67	9.73	1.21	3.01	0.57
Relative price of livestock (in natural logs)	21.34*	1.77			17.98	1.56		
Distance to market (in natural logs)	–1.88	–0.73			–2.07	–0.81		
Years cultivating	0.47**	2.73			0.51**	2.96		
Stock densities (est.)	0.31	0.06	–2.50	–0.81	1.7	0.34	–3.67	–1.15
NonCoop (normalised)	–1.13	–0.12	9.98*	1.7				
Coop (normalised)	–13.44*	–1.62	–7.46	–1.38				
In-migration of animals					–0.73	–0.66	1.47*	1.92
Dummy for community animals out-migrating					6.02	1	–2.10	–0.53
Members engaged in wage work (%)					0.07	0.87	0.07	1.33
Heterogeneity in wealth					0.36	0.28	1.69*	1.88
Constant	–36.27	–0.76	21.73**	4.05	6.7	0.12	0.87	0.02
R^2	0.54		0.39		0.54		0.42	
Sample size	36		36		36		36	
CV = coefficient of variation; * = significant at the 10% level; ** significant at the 5% level.								

The coefficients are similar in the land allocation equations to those obtained with the full sample, and all the R^2 remain the same. However, in the specification using the co-operation indices, two coefficients are now statistically significant—a positive coefficient on prices and negative coefficient on Coop. Contrary to the hypothesis that more land would be allocated where grain prices were relatively high, the sign of relative price variable is positive in all four specifications. The CV of rainfall is positive but just shy of being significant at the 10% level, indicating perhaps a weak effect of crops as a risk management tool. More interestingly, neither average rainfall nor total households have any impact on land allocated to crops, all else being equal. Coop is negative, indicating that higher levels of co-operation lead to less land being allocated to crops, as hypothesised. In the second specification for cropland allocation, we return to a situation where only the years cultivating variable is significant.

Unlike the case for cropland, the reduced sample leads to significant changes in the estimations. The R^2 improve rather dramatically, more coefficients are statistically significant, and the size of the coefficients changes. In particular, average rainfall now has a statistically significant negative impact on per cent land allocated to private pastures; the CV has a positive and significant impact in the first specification, which loses significance in the second. The NonCoop variable is positive as expected; Coop is negative, but not statistically significant. Of the exogenous co-operation variables replacing the indices in the second specification, the in-migration variable has a positive effect, as does heterogeneity in wealth.

5 Conclusion

In general, many of the hypotheses generated by the conceptual model are borne out in the data analysis. Communities with a lower index of non-co-operation and a higher index of co-operation, or those with less heterogeneity and less in-migration, have lower stocking densities. Even though there were no explicit rules regarding stock holdings at the individual level or well-defined limits on stock densities at the level of the community, the empirical results give strong evidence that there is in fact a mechanism in place to reduce overstocking, but the efficacy of this mechanism appears to differ across communities. Of the variables hypothesised to affect the level of co-operation reached, in-migration and heterogeneity had a consistent non-co-operative impact directly on the co-operation indices and the stock density equations and, to a lesser extent, on percentage of land allocated to private pastures. Though the land allocation equations are not very robust, co-operation seems to play a bigger role in reducing land allocated to crops (Coop being significantly related to highly variable communities with relatively greater numbers of households and where relative livestock prices were favourable), and land allocated to pastures responded more to non-co-operation (NonCoop being significantly related to communities with many households, a high degree of heterogeneity, little out migration but heavier in-migration and a larger per cent of members engaged in outside wage work).

The additional effect of increased households on stock densities is also consistent with non-co-operation and with increased stock densities above those associated with socially optimal rates; to the extent that ‘complete’ co-operation cannot be reached, the degree of overgrazing will be a function of the number of members. There is limited evidence of intensification of animal production—i.e. there is very little use of purchased feeds/concentrates or other inputs—that might otherwise support an hypothesis of population-driven intensification allowing for more animals per hectare without decreasing output per hectare or total output. Indeed, the haymaking dummy (admittedly a crude measure) was not significant in either stock density equation.

Market prices and range quality have two distinct, and offsetting, effects on stock densities. The direct price and range quality responses are positive, but higher prices and better range quality also appear to lead to greater levels of co-operation, as reflected in the estimated equations for NonCoop and Coop. Market distance had no significant effect on co-operation, stock densities or land allocation. Whereas livestock are mobile, the lack of effect on land allocation, particularly to crops, is somewhat surprising.

Though results from the land equations are not entirely satisfying, the evidence does support the hypothesis that current changes in land use patterns—increases in both private pastures and cropped land—are, in part, a function of the desire of individuals to diminish negative externalities associated with use of common pastures. Unlike the stock density equations, however, the impact seems to be captured completely by the co-operation variables; there does not appear to be an additional impact via increased households, as would be expected. The number of years a community has been cultivating has a robust positive impact on the per cent of land allocated to crops; an increase in a year’s experience with cropping increases the per cent of cropland by just under 0.5%.

Thus, both anecdotal evidence and empirical results from this study support the notion that cropland and private pastures are related to permanent structural changes in land allocation, rather than temporary responses to rainfall shocks. Increased allocations of land to private uses may improve household incomes and reduce variability in output up to a point, but it appears that 'too much' land is becoming privatised in some communities, due to lack of co-operation over pasture management and land allocation provisions. In these cases, co-operation can mitigate the tendency to over-allocate land to private uses. One of the key elements in fostering co-operation will be methods for handling the increased heterogeneity among community members and in more effectively managing the communities' relationship with outsiders who use community pastures. Nonetheless, few variables were robust across the land allocation equations, and the estimations performed poorly for the entire sample. Because the area of land dedicated to private uses is apparently increasing every year, a better understanding of the factors driving such changes is necessary.

Finally, we note that the CV in rainfall has a significant positive impact on the level of co-operation as captured in Coop and also has a significant negative impact on stocking rates in communities that are described as non-equilibrial. Thus, areas with high coefficients of variation of rainfall have lower stocking rates due to both a direct negative impact and to an indirect effect through co-operation. The direct effect is interesting in and of itself; as noted above, many researchers have called for a complete rethinking of rangeland management in the semiarid and arid regions, have derived policy recommendations for pastoral development and resource management and have been somewhat successful in getting donor projects in adopting some of these recommendations. However, many of these recommendations are based on the assumption that pastoralists hold relatively large numbers of animals precisely because of environmental variability. In other words, in the face of fluctuations in livestock outputs and herd sizes due to environmental variability, the best option (all else being equal) for the pastoralist is to hold large herds. The implication is that a reduction in variability of livestock outputs would lead to a reduction in herd sizes. Again, our results are not consistent with this argument, and suggest that any policies aimed at mitigating the impact of rainfall variability on livestock production must first consider the impact on community-level co-operation in the management of common pool rangelands, and must also recognise the fact that stock densities may in fact increase.

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Appendix I. Descriptive statistics

Variable	Low rain, Low CV		Low rain, High CV		High rain, Low CV		High rain, High CV	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Average rainfall	451.25	62.21	436	39.55	696.67	47.22	711.36	184.18
CV rainfall	0.3	0.07	0.48	0.02	0.27	0.05	0.48	0.1
Total households	38	29.93	27.38	16.35	69.58	33.54	157.09	119.2
Total hectares	1176.94	439.3	1166.91	876.96	1089.23	517.93	1203.64	769.19
Stock densities	0.92	0.9	0.64	0.61	0.78	0.34	1.78	1.98
Land in crops (%)	2.5	4.1	8.75	4.43	19.58	16.29	25.46	15.88
Land in private pasture (%)	14.5	5.98	23.12	6.51	18.83	24.65	15.45	11.5
Relative price of livestock	0.74	0.02	0.72	0.02	0.91	0.18	0.91	0.25
Distance to market	59.75	36.11	49.38	29.34	28	21.92	38.81	24.89
Range quality Index	3.38	1.69	3.25	1.67	2.42	1.62	3	1.55
Hay	25.2	46.29	12.5	35.35	17.24	39.18	64.32	50.44
Years cultivating	3	4.41	4.5	5.32	18.83	16.21	18.45	10.23
CV = coefficient of variation; SD = standard deviation.								

Appendix II. Regressions of stock levels

	Stock level		Stock level	
Dependent variable	Coefficient	t-stat	Coefficient	t-stat
Total hectares (in natural logs)	0.38*	1.96	0.31**	2.34
Total households (in natural logs)	0.75**	5.56	0.89**	10.83
Haymaking	0.42	1.48	–0.07	–0.27
CV of rainfall (in natural logs)	1.23	1.58	0.55	0.67
Dummy for high CV	–3.41**	–2.75	–1.80**	–2.42
Dummy* CV	–3.42**	–2.93	–2.21**	–3.11
Relative price of livestock/grain (in natural logs)	0.52	1.11	0.3	0.8
Distance to market (in natural logs)	–0.006	–0.04	–0.03	–0.18
Range quality index	0.09*	1.72	0.09	1.22
NonCoop (normalised)	0.6	1.59		
Coop (normalised)	–0.86*	–2.02		
In-migration of animals			0.13**	3.85
Dummy for community animals out-migrating			–0.07	–0.26
Members engaged in wage work (%)			–0.001	–0.22
Heterogeneity in wealth			2.13**	3.47
Constant	2.51	2.08	0.35	0.22
Adjusted R^2	0.71		0.78	
Sample size	39		39	
CV = coefficient of variation; * = significant at the 10% level; ** significant at the 5% level.				