Paper 26b
September 1988

A MODEL OF HERD COMPOSITION THAT MAXIMISES HOUSEHOLD VIABILITY AND ITS POTENTIAL APPLICATION IN THE SUPPORT OF PASTORALISTS UNDER STRESS

by

Ruth Mace

Renewable Resources Assessment Group, Centre for Environmental Technology, Imperial College, 48 Prince’s Gardens, London SW7 1LU.

This research was supported by the Natural Environment Research Council and the International Institute for Environment and Development.

A model of herd composition that maximises household viability and its potential application in the support of pastoralists under stress

Ruth Mace

INTRODUCTION

A common aim of the poor has been described as a secure and decent livelihood (Chambers 1983). In the rural areas of poorer countries, most people strive to achieve this through farming. When the farming system is under the control of the rural people themselves, it is reasonable to assume that in many cases its primary objective will be to ensure the long-term maintenance of that livelihood. Most economic analyses of such systems explicitly or implicitly value them in terms of some measure of output. These productivity measures may represent the utility of the system to some external but interested party, such as a government, but do not necessarily reflect the utility of the system to the producers themselves. Households are constrained by the need to raise some basic level of food and income - enough to meet their subsistence needs - every year. In this paper I describe a model, developed by Mace and Houston, which illustrates how, in unpredictable environments, maximising the short-term mean level of output and maximising the long-term viability of the households producing that output are not necessarily the same thing. The most rational option for the household is to maximise the latter, which may involve increased diversification and lower rates of offtake than the former. Suggested "improvements" to management practices that increase productivity may not be sustainable because they reduce household viability. This is a model of a livestock production system which evaluates herding strategies, and the impact of external events upon them specifically in terms of their effect on the long-term maintenance of a basic standard of living for the pastoralists.

WHY USE MODELS?

Policy makers tend to make decisions about the potential costs and benefits of intervening in pastoral systems on the basis of informed guess-work. In many ways models will operate in the same way - so are they any extra use?

Someone with experience of herding in a particular environment may get a feel for certain relationships, such as the relationship between number of livestock owned and household viability, or more complex interactions such as the effect that a quantity of food aid or price support for livestock carcasses may have on the proportion of families that are likely to be able to support themselves whilst recovering from drought. A modeller will attempt to predict these relationships by identifying underlying processes and using a computer to see how these processes lead to different outcomes with different probabilities. If those with first-hand knowledge of the system predict very different outcomes from the computer models, or if data contravenes predictions made by the model, then the assumptions on which the model operates can be reevaluated. In this way an understanding of the dynamics of the system can be built up. In situations where no-one has a very good feel for the effect of particular interventions, perhaps because the situation has not arisen before or the proposed intervention is new, the a model that has been built up can be used to help policy makers see how particular assumptions lead directly to different expected outcomes. Hence modelling can serve several purposes. It may help formulate ideas about the processes, which those with first-hand knowledge may understand "instinctively", either for the benefit of others (e.g. those facing related problems elsewhere or those whose actions may impinge on the system deliberately or inadvertantly, such as external policy-makers’ decisions on pricing, destocking, restocking or whatever), or by increasing or decreasing confidence in predictions about the outcome of interventions in new situations.

The particular model described here attempts:

i) to predict the type of stock a household should keep to maximise its long-term viability (and how that may change with household wealth).

and

ii) to estimate the probability of that household remaining viable, depending on the number of stock held.

The first prediction provides a mechanism for testing the validity of the model, for if people do keep the ratios of stock predicted it suggests the model has successfully identified key processes, constraints and objectives. The second prediction has potential practical application, which is described in more detail later in the paper.

THE MODEL

The case described here is a general model of a camel and small stock subsistence pastoral system. The technique used is stochastic dynamic programming (Ross 1983, Whittle 1983) - a numerical technique which can provide precise answers to particular questions, such as what is the probability that a household with livestock wealth *y* will survive for *x* years in a particular environment? It is not my intention here to describe the mathematics, which is covered in Mace & Houston (in press), along with a more detailed description of the assumptions of the model. I simply wish to outline the processes in the model, describe the results it generates and then finally discuss the uses to which such a model can be put.

A model of a livestock production system should include both the biological processes (such as fertility, natural mortality etc.), which may be largely determined by the environment, and economic processes which depend on decisions made by the herder (such as sale or slaughter and how these contribute to household needs). This model, which considers how pastoralist households minimize the risk of destitution rather than maximise some form of production, must incorporate how the biological processes are influenced by drought and also how the human manipulation of the herd is likely to change when the household is under stress.

Fig. 1 shows the ecological/economic model of the system, on which the mathematical model is directly based. These are the processes assumed to operate on a household herd each year. The herd considered includes all the species owned by the household, ie. camels and small stock in this case. Only adult females are considered explicitly and a household is considered no longer viable if it has no breeding stock left. The only labour constraint explicitly included is a maximum herd size. In this model it is lack of livestock that is considered as the major threat to household viability.

Figure 1 indicates the ecological processes. The parameters that have to be put into the model are listed in Table 1. The values given in the baseline example are within the range estimated by Dahl & Hjort (1976) for camels and goats in northern Kenya. A female of each species is considered to have a particular probability of giving birth to a surviving female and a probability of dying in a year if there is rain and another set of fertility and mortality probabilities if there is drought. Small stock herds grow at very much faster rates than camel herds but are liable to heavy losses in droughts. Even taking droughts into account, small stock herds are assumed to grow on average at three times the rate of camel herds. Droughts are assumed to occur randomly with a specified probability and the probability of a drought occurring next year is not influenced by whether or not one has just occurred. This seems to be the case at least in the East and Horn of Africa (Farmer 1986). Hence variance in herd growth will depend on random fluctuation in the number of female births and deaths and also on fluctuations in rainfall. Note that the proximate causes of mortality (eg. disease, starvation, raiding etc) are not included explicitly but values are simply assigned to drought-related and non-drought-related probabilities of loss (in practice most drought-related loss will be caused by disease in weakened animals).

Most of the processes in Figure 1 are almost always included in models of pastoral systems, although sometimes the influence of droughts is omitted. Any deterministic model cannot, of course, take account of variability in herd growth rates and can only incorporate drought either as a once-off event or something that occurs with a strict, regular periodicity. This is unrealistic and hence limits the use of such models - only stochastic models can incorporate droughts as recurrent yet unpredictable events.

Figure 2 indicates sale and slaughter. As the model only considers breeding stock explicitly, then this is only likely to occur when the outstanding needs of the household cannot be met from dairy production and the sale or slaughter of males. This is incorporated by defining a subsistence requirement to be met by the herd (ie. what is needed when any other sources of income have been taken into account), which is the herd size at which the milk from females and the meat yield from males, or the food bought by selling those products, can support the household. If the herd does not produce this requirement than enough females have to be sold or slaughtered (whichever contributes most) to make up the deficit. This has the effect of reducing the herd size but does not automatically lead to destitution due to the stochastic nature of the environment. If there is successful breeding the following year losses can be more than recovered. Values for the yield and the purchasing power of an animal and also the household subsistence requirement can differ in drought and normal years.

The process of increased female offtake at low herd sizes is seldom incorporated in models of pastoral systems, perhaps because it is generally easier for the modeller to assume that herder strategies and maybe even wealth remain fixed. This may not matter for some purposes but if long-term viability is being considered it is important that this is included.

Figure 3 indicates the exchange of one species for another (or the sale of one species in order to buy another) ie. the adjustment of the mixture of species kept. The composition of the herd is assumed to be a conscious decision of the herder. Pastoral herds cannot be considered simply as wild populations, nor can pastoralists be considered as passive herders whose herds are purely products of circumstance. Whereas a herder will be constrained by his or her total livestock wealth, if, for example, he or she had accumulated a very large herd of small stock but had no camels then some of the small stock could be sold and camels bought if that was thought to improve the composition of the herd.

The rules governing these processes are generated by the model. That is, it calculates the optimal mixture of small stock and camels for each level of wealth, given the ecological and economic parameters used to describe the herder’s environment. Optimal, as used here, means the mixture that minimises the chance that the household’s requirements will not be met by the herd, now or at any time in the future, ie. that maximises the long-term viability of the household. So the model takes account of the fact that herders will adjust the composition of the herd (through preferential slaughter or exchange) to the optimal mixture, should their wealth change. As the herder will be continually trading off reliability and productivity or potential for growth when deciding what mixture of species to invest in, the consideration of how best to do this is conceptually similar to what an economist would call "portfolio analysis".

In this respect, this model differs from all other existing models of pastoral systems. The number of ways in which herd composition can be changed according to fluctuating wealth is virtually infinite and therefore all possible strategies cannot be compared using simulation runs. Dynamic optimization is a far more powerful technique which enables the optimal policy (or set of species mixtures depending on wealth) to be precisely calculated. The vital importance of incorporating such flexibility in herding strategy is illustrated later.

If attempting to make quantitative predictions about a particular system, it would be necessary to make adjustments and elaborations to these assumptions. My intention here is to describe a model capable of incorporating relevant processes, to seek general, qualitative trends and to identify which parameters are likely to have the greatest influence on herders' strategies - and thereby increase our understanding of the dynamics of such systems.

Note that the model runs on a few, key parameters (Table 1). In systems where variability is high, this may be a more useful approach than attempting to identify a whole range of parameters that some others such as the widely used Texas A & M model demand.

RESULTS

Optimal species mixtures

The model predicts that the ratio of camels to small stock that minimizes the long-term risk of losing the herd will vary considerably according to the overall wealth of the household. The optimal species mixture for households of different wealth in the baseline case are shown in Fig. 2.

Poorer households should not invest in camels. Only when total livestock wealth is greater than 84 female goat equivalents should both species be kept. Above this critical limit, the majority of the household's wealth should be invested in camels. This is despite the fact that the growth rate of small stock herds is, on average, three times faster than that of camels. Some small stock should be exchanged for a camel if their numbers increase above the optimal level. Hence, according to the model, if its herd is increasing, a household would be more likely to exchange small stock for a camel than vice versa but after a large decrease in herd size a household might do better to exchange its camels for small stock, buying back camels only when the herd size has increased later. This process has been described qualitatively for various pastoral systems (Spencer 1973, Toulmin 1983, Ellis et al. 1987).

Figure 3 shows the effect on the optimal policy of varying the mortality suffered by small stock in droughts. When the probability of a goat dying in drought is set at 85% (ii), the mean camel and goat herd growth rates (over all years) are equal. As the exchange rate (or relative price) of camels and goats is set at the ratio of their food yields, there would be no obvious advantages of one species over the other in terms of its contribution towards the household subsistence requirement or towards future increases in herd size or wealth. This example is rather unrealistically severe but it does enable an evaluation of the benefits of keeping two species which differ only in the risks associated with them. There is some deviation in favour of camels from the baseline optimal policy but it is not great, indicating the robustness of the model with respect to variation in some parameters. Even when mean goat herd growth rates are five times that of camels (iii), the wealthier households still do better to invest largely in camels.

One parameter which emerges as imposing a significant influence on the relationship between optimal species ratio and wealth is the household subsistence requirement. The estimate of 80 female goat equivalents (or 10 female camel equivalents) is roughly that made by Dahl & Hjort (1976). Their estimate is based on the assumption that the family is fed entirely on livestock products, which may have been the case in the past but is now uncommon. This figure could be reduced if, for example, livestock products can be exchanged for grain at a favourable rate or if a relative in paid employment was sending money home or if the pastoralists were in receipt of long-term food aid. Indeed current pastoralist population densities may be insupportable in some areas without such practices, the exchange of meat for grain being particularly important (Upton 1986). Figure 4 (ii) shows the influence of lowering the household subsistence requirement. The point at which households should start investing in camels is when the herd size is just above that which produces the household subsistence requirement. Hence one would expect the exact species ratio of any particular household to depend on the size (and therefore requirement) of the household and also on all its income, not just that gained from the herd. Only if there was no supporting income and no variation in household requirements would all families in a system follow identical strategies. It is common that the relative price of grain and livestock products becomes very unfavourable for pastoralists in drought (Toulmin 1983). This would effectively increase the herd size needed in bad years. Figure 4 (iii) shows the effect of having a lower value for the household subsistence requirement in normal years than in drought years - the point at which herds should become mixed is somewhere between the two herd sizes.

The results are all presented as the *proportion* of wealth invested in each species. Obviously the ratio of camels to goats *in number of animals* depends on their relative value, being lowered if the camels are more expensive or increased if they are cheaper. As data on household holdings would normally be collected in numbers of animals, it is important that information is found on their relative price or exchange rate before such data can be compared with the quantitative predictions the model makes about herd composition. (It also should be said that the amalgamation of data on different species into TLU’s or some other single unit obviously makes them useless for this purpose).

These results are fairly robust and a considerable degree of uncertainty in the estimation of some parameter values need not alter the predictions about basic principles of herd composition. An outstanding feature of all cases modelled (of which those presented here are just some examples) is the existence of a critical boundary, related to the household requirement to be met by the herd, below which only small stock should be kept and above which mainly camels should be kept. Some parameter values may vary between different households even in the same system, so, if observing field data on wealth and herd composition over a number of families, one would not necessarily expect to see the abrupt discon- tinuity shown in any one particular policy but more likely smoother trends obtained by averaging over many such policies.

Quantifying household viability

Values of expected household viability can be extracted directly from the model. Figure 5 illustrates how keeping the optimal mixture of species for your wealth promotes long-term viability. The proportion of households, with an initial herd size of 80 female goat equivalents, expected to survive in the system is shown over 50 years. Households following the optimal policy are compared with households of the same initial wealth following two other simple strategies: keeping only goats and keeping the maximum number of camels (ie. keeping a few goats as "small change" but always exchanging them for a camel once there are sufficient). These latter policies do not include changes in strategy with wealth. The graph shows that keeping only goats (ie. not exchanging them for camels at higher herd sizes) is disastrous in the long term with only 4 families in 1,000 remaining after 50 years (in this hypothetical environment). As the average growth rate of goat herds is set at three times that of camels, a deterministic model would have found that this was the strategy with the highest returns! The policy of keeping the maximum number of camels (even at low wealth) is more successful but doesn’t match the optimal policy. Note that if pastoralists were only interested in a two or three year time horizon this policy would actually be best because it avoids the risk of rapid losses when only goats are kept at lower herd sizes. However the avoidance of this risk does nothing to promote long-term survival because a larger proportion of the households following this strategy, although not losing their herds immediately, are trapped by slowly declining herds that are just too small to meet household requirements so some females are having to be sold off each year. If they were to keep mostly camels in these circumstances then their herd growth would normally be too slow for households to break out of this vicious cycle, leading ultimately to lower survival chances. Comparing these three policies illustrates the vital importance of herders adjusting their strategies according to their wealth.

Figure 5 shows the effect of wealth on long-term viability by comparing the expected survival of households with three different initial herd sizes over 50 years. No herd size can ensure indefinite survival due to the unpredictable nature of herd growth. After 10 to 20 years the *rate* at which households are lost from the system becomes constant and independent of initial herd size (3 families per 1,000 per year in this case). This is because the families remaining are those that have succeeded in establishing large, mixed herds. The proportion of families achieving this does depend critically on initial herd size. Such calculations could be useful to relief agencies considering restocking destitute pastoralists with new herds (see Application).

Household viability estimates are more sensitive to variation in parameter values than are optimal species mixtures, so generalised quantitative predictions cannot be made. Yet quantifying viability in particular cases, as has been done here, does allows two important general points to be emphasized. First, there is no such thing as "a minimum viable herd size". The term is meaningless unless some specified level of viability is included in its definition, e.g. the probability of herd loss is less than 1% a year. Second, if the viability of a herd is calculated by dividing the mean output of the herd by the requirement of the household and sighing with relief if the answer is greater than 1 (which occurs at herd size 80 in the baseline case), this does not mean that everyone will survive (30% of households starting with 80 goats would be expected to have dropped out of this system in 10 years).

DISCUSSION

The model predicts how a pastoralist household should divide its wealth between camels and small stock in order to maximise its long-term viability. Some general principles emerge. These are that a household should invest only in small stock if it is roughly on or below the minimum herd size that produces enough to feed the household without selling off female animals. Once the herd size has exceeded this critical limit by a small margin it generally becomes beneficial to invest most of the household wealth in camels, but the extent to which it should invest depends mainly on the mean and variance in goat growth rates and on the relative price of the two species. Hence these are parameters about which something should be known before reasonable, quantitative predictions about optimal herd composition in any particular system can be made. The expected, long-term viability of household herds in a particular system can then be quantified.

These strategies minimise the risk of starvation. As camel herds are not subject to large annual fluctuations in growth rate caused by drought, it might seem that "risk minimizers" should simply invest all their wealth in camels. This is not so for two reasons. First, camels are a larger unit of investment and, although a camel is less likely to die than is a goat, if it did die the loss could not be borne by a poor household. Selling the camel and buying eight goats instead does spread the risk to some extent. Second, a herder with a herd too small to meet the household subsistence requirement needs to gamble on a lack of drought that will give some chance of herd size increasing. If it did not increase sufficiently, females would have to be sold or slaughtered to meet basic needs, which could trap the herder in a vicious cycle of decreasing herd size from which it would be particularly difficult to escape with a slow-breeding species like a camel. It is often stated that poor people are risk averse (Lipton 1968). This model shows that minimizing the risk of starvation is not necessarily the same thing as opting for modes of production with the lowest variance in output. In extreme poverty the most rational options may involve substantial risks.

If a pastoralist household or society is found to be following the general, qualitative predictions made by the model in their herd management, then this would suggest that the objective maximised in the model was indeed important to those people and that they are taking a long-term view. This model does not necessarily tell us how absentee herd owners with bank accounts and enough other revenue to meet basic needs would manage their investment in livestock. I *would* expect the predictions of the model to apply to those whose livestock makes a vital contribution to the household economy.

APPLICATION

If a model successfully describes the dynamics of a system, it can have considerable practical application. The impact of particular events, such as two consecutive years of drought and the time taken to recover from it, can be estimated. Using parameters values that are measurable (such as rainfall or percentage of livestock lost), the model can enable more difficult estimates to be made (such as the long-term viability of remaining households) which may be of more direct relevance when trying to estimate the effect on human beings. Because the model used here is both stochastic and dynamic it contains a greater degree of ecological and economic realism. Simple, simulation models that fail to take account of dynamic processes can produce misleading forecasts about the ability of pastoralists to recover from drought.

Two examples of how the planning of interventions into pastoral systems can be helped by such a model are described below: one is restocking and one is food aid to pastoralists.

Figure 6 shows how families with different herd sizes have different probabilities of becoming destitute. If stockless families are to be restocked, the donor of that stock may wish to know how many stock to give to each family in order to make the best use of limited resources. Figure 7 evaluates each potential restocking package or herd size in terms of the number of families that will be self-supporting for at least 10 years per goat donated. It shows that if too few animals are given the scheme is actually expensive as many of these families will not achieve self-sufficiency. If families are given too large herds then money is also in some sense wasted because, although the restocked families are very successful, fewer families can be restocked. Quantitatively, the graph shows between 70 and 100 goat equivalents per family is best, ie. the same number of families would be expected to survive independently for at least 10 years if 100 families are given 70 goats or 70 families are given 100 goats (in this example), but if families are given smaller or larger allocations then the maximum number of self-supporting families per pound spent will not be achieved. It should be noted that, in this example, allocations of over about 80 goat equivalents should contain mostly camels. Allocations below this amount, which should be given in small stock, could lead to very great local demand for large stock a year or two after restocking if there was rain and many herds had increased. Of course there are many other considerations that have to be taken into account before decisions are arrived at, but this process can provide a framework for estimating outcomes.

To illustrate this quantitatively, imagine that a donor agency had £96,000 to spend on stock for an area. If each goat cost £20 then 4,800 goats could be bought (if available). If it was decided that each family should be given 60 goats then 80 families could be restocked. The model predicts that, if the families selected were those with no other source of income, each has roughly a 55% chance of being unable to feed itself at some stage over 10 years, meaning that one would expect about 36 families to remain viable after 10 years, ie. £2,667 per successfully rehabilitated family. If it was decided to give each family 80 goats, meaning that only 60 families could be restocked, then the model estimates that each has a roughly 30% chance of falling destitute at some point over 10 years, so about 42 families would be expected to remain after 10 years, ie. £2,286 per successful family - or 15% more rehabilitated households for the same input.

Figure 8 shows how giving food aid to pastoralists may influence their chances of remaining viable. Food aid to families with some stock but not enough to meet their needs for very long means the chances that they are forced to sell off breeding stock simply to survive can be reduced. Hence this helps them restock themselves. In this example, the proportion of families with initial herds of 80 goats that would be expected to remain viable is shown with and without half the households subsistence requirement being guaranteed by an external donor. Once again, such calculations can help donor agencies estimate the efficacy of particular options, especially if they have some information on the stock wealth of the families they are helping, and hence provide a framework within which different options can be considered. The dotted line shows the expected increase in viability if families continued to buy into large stock at the optimal point for an 80 goat equivalent requirement rather than 40 (ie. follow the policy they would if the donor was not there). This shows that if the families are unaware or uncertain that this donation of food will be available should they need it, then they may not be able to make as much use of it as if they were sure it would be provided. This illustrates a possible benefit of long-term policies by donor agencies and trust between donor and recipient over and above those that are obvious.

Advice from recipients of aid may be a useful source of information for making such decisions. Trial and error is a common method of attempting to resolve these kinds of questions, which will always provide more reliable information than a model, albeit at some cost. Long-term effects, which are arguably the most important, are also the most difficult for anyone to predict. The process will always involve speculation. Modelling provides a complementary basis for arriving at such predictions. It is, I have argued, a potentially useful tool to help ensure that opportunities to make better use of aid resources are not overlooked.

CONCLUSIONS

The main purpose of model building is to improve our understanding of systems. Many studies of pastoralist systems have arrived at the conclusion that herding strategies are rational and efficient and only appear otherwise if objectives different from those of the herders themselves are assumed. This model is another step down that path. It demonstrates that the objective of long-term survival or long-term maintenance of a livelihood can be formalised in a model and that such a model predicts optimal herding strategies which do qualitatively resemble those practiced. Such a formalization could be of direct help, not so much to those attempting to redesign such systems, but to external donors who attempt to support existing systems facing crises and who want to estimate the possible effects of their interventions.

REFERENCES

Chambers R. 1983. Rural Development: Putting the Last First. London: Longman.

Dahl G. & A. Hjort. 1976. Having herds: pastoral herd growth and *household economy*. Stockholm Studies in Social Anthropology. Stockholm: Department of Social Anthropology, University of Stockholm.

Ellis J.E., Galvin K., McCabe T. & D. M. Swift. 1987. *Pastoralism and Drought in Turkana District, Kenya. A Report to Norad.* Bellevue, Colorado: Development Systems consultants, Inc.

Farmer, G. 1986. "Rainfall Variability in Tropical Africa: Some Implications for Policy." *Land Use Policy* 3:336-342.

Lipton M. 1968. "The theory of the optimising peasant." *Journal of Development Studies* 4:147-152.

Mace R. & A. Houston. In prep. Pastoralist strategies for survival in unpredictable environments: a model of herd composition that maximises household viability.

Ross S. 1983. *Introduction to stochastic dynamic programming*. New York: Academic Press.

Spencer P. 1973. *Nomads in alliance. Symbiosis and growth among the Rendille and Samburu of Kenya*. London: Oxford University Press.

Toulmin C. 1983. "Economic behaviour among livestock-keeping peoples: A review of the literature on the economics of pastoral production in semi-arid zones of Africa." *Development Studies Occasional Paper 25*, Norwich: University of East Anglia.

Upton M. 1986. "Production policies for Pastoralists: the Borana case." *Agricultural Systems* 20:17-35.

Whittle P. 1983. *Optimization over Time, Vol. 2*. Chichester: John Wiley.

Fig. 1. Ecological/economic processes included in the model which influence the size and composition of a household herd of female camels and goats in a year.

Fig. 2. Optimal division of wealth between goats and camels, for herd sizes 0 to 160, in the baseline case. Cross-hatching represents wealth invested in small stock and dark shading represents wealth invested in camels. Wealth is measured in goat equivalents and eight goats are equivalent to one camel (zig-zags result because camels are a relatively large unit of investment, and the addition of each new camel to the herd causes a jump in proportion of wealth invested in camels). All parameter values are shown in Table 1 (the baseline case).

Fig. 3. The influence of goat mortality in drought on the optimal division of wealth between goats and camels. (i) Mean goat mortality in drought is 55%, ie. the baseline case (same information as in Fig. 1). (ii) Mean goat mortality in drought is 85%, ie. mean annual growth in goat herds is the same as that of camel herds. (iii) Mean goat mortality in drought is 25%, ie. annual growth in goat herds is five times that of camel herds. All other parameter values are as in Table 1.

Fig. 3. The influence of goat mortality in drought on the optimal division of wealth between goats and camels.

(i) Mean goat mortality in drought is 55%, ie. the baseline case (same information as in Fig. 1).

(ii) Mean goat mortality in drought is 85%, ie. mean annual growth in goat herds is the same as that of camel herds.

(iii) Mean goat mortality in drought is 25%, ie. annual growth

in goat herds is five times that of camel herds.
All other parameter values are as in Table 1.

Fig. 4. The influence of the household subsistence requirement (hsr) on the optimal division of wealth between goats and camels. (i) hsr=80 goat equivalents (baseline case). (ii) hsr=40 goat equivalents. (iii) hsr=40 in normal years and 80 in drought years. Other parameter values as in Table 1.

Fig. 4. The influence of the household subsistence requirement (hsr) on the optimal division of wealth between goats and camels.
(i) hsr=80 goat equivalents (baseline case).
(ii) hsr=40 goat equivalents.
(iii) hsr=40 in normal years and 80 in drought years.
Other parameter values as in Table 1.

Fig. 5. The influence of households, with an initial herd size of 80 goat equivalents, remaining in the system over 50 years when i) following the baseline optimal policy, ii) keeping the maximum number of camels, iii) keeping only goats. All parameter values are as in Table 1.

Fig. 5. The influence of households, with an initial herd size of 80 goat equivalents, remaining in the system over 50 years when
i) following the baseline optimal policy,
ii) keeping the maximum number of camels,
iii) keeping only goats.
All parameter values are as in Table 1.

Fig. 6. The proportion of households (following the optimal policy) remaining in the system over 50 years with initial herd sizes of (i) 100 goat equivalents (ii) 80 goat equivalents (iii) 60 goat equivalents. Parameter values are as in Table 1.

Fig. 6. The proportion of households (following the optimal policy) remaining in the system over 50 years with initial herd sizes of (i) 100 goat equivalents,
(ii) 80 goat equivalents,
(iii) 60 goat equivalents.
Parameter values are as in Table 1.

Fig. 7. The expected cost of using different restocking herd sizes in terms of goats donated per viable household achieved (viable means still surviving as pastoralists 10 years later). Parameters used are as in Table 1.

Fig. 8. The effect of food aid on number of households expected to remain in the system over 25 years. (i) Proportion expected to survive in the system without help (ie. household subsistence requirement is 80 goat equivalents) (ii) Proportion expected to survive if half household subsistence needs are provided (ie. household subsistence requirement to be met by the herd is 40 goat equivalents. (iii) Proportion expected to survive when the household subsistence requirement is reduced to 40 but pastoralists continue to follow the optimal policy for a subsistence requirement of 80. Other parameters used are as in Table 1.

Fig. 8. The effect of food aid on number of households expected to remain in the system over 25 years.
(i) Proportion expected to survive in the system without help (ie. household subsistence requirement is 80 goat equivalents) (ii) Proportion expected to survive if half household subsistence needs are provided (ie. household subsistence requirement to be met by the herd is 40 goat equivalents.

(iii) Proportion expected to survive when the household subsistence requirement is reduced to 40 but pastoralists continue to follow the optimal policy for a subsistence requirement of 80.

Other parameters used are as in Table 1.