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Resource Allocation in Socio-Ecological Systems: Implications for Sustainable Rangeland Management in Kenya

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Abstract: This paper explores resource allocation decisions in Kenyan rangelands. We analyze choice decision of the producer to enter or not to enter livestock production, and the determinants of the optimal herd size. We apply the Heckman two-stage estimation procedure to correct for selectivity bias in the livestock production, optimal income and optimal herd size process. The results show that tenure security, assets and location of the household are important determinants of the decision to hold livestock and the optimal stocking rates and incomes. We find no evidence of selectivity bias in the decision to hold livestock, but there is self-selection in participation in livestock production and the optimal stocking rates. Main barriers to sustainable range management are identified to include population pressure, institutional constraints and poverty. Strategies focusing on elimination of these barriers are recommended.

Key words: Sustainable range management, optimal herd size, rangelands, Kenya.

Nearly half of the world's soil resources are degraded. It is estimated that overgrazing causes 35% of all human-induced soil degradation worldwide and that between 1945 and the 1980s, overgrazing was the prime cause for about half of the degraded land in Africa (Haen, 1993; Pinstrup-Andersen and Pandya-Lorch, 1994). Available evidence from Kenya also indicates that livestock activities have contributed to environmental degradation especially in the arid and semi-arid areas, which are characterized by a limited natural resource base and low carrying capacity (Republic of Kenya, 1999). This is attributed to the nature of pastoral systems[1] adopted by herders. Pastoral production has been described as ecologically destructive due to the long-term impact of livestock accumulation on rangeland conditions. The tendency to retain or increase cattle numbers even under adverse environmental conditions is a widespread and characteristic feature of many African countries (McPeak, 2000). The impact of increased degradation of land in these areas is declining herds, output, widespread and rising levels of poverty[2]. This induced-poverty further leads to spirals of overgrazing and resource degradation as the poor struggle to satisfy their short-term needs for pasture, food and firewood.

To reduce the level of degradation in rangelands and to reduce the escalating levels of poverty and vulnerability, optimal resource allocation and sustainable development of

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1 Pastoral systems are systems of natural resource use in which free ranging or grass-fed animals are the principal means of exploiting the resources

2 Empirical evidence shows that poverty in Kenya highest is marginal grazing lands (Mwabu *et al.*, 2000).

the rangelands are critical concerns for any policy intervention. The sustainable use of grazing lands requires effective range management in the wake of increasing population pressure, overgrazing and encroaching desertification[3]. Investing in pastoralism requires balancing political, social, economic and environmental considerations to arrive at the conclusion that investment is worthwhile or sustainable. Furthermore, the interaction of socio-economic relationships is important in determining sustainable development of such systems. These relationships include the nature of the livestock resource, mobility, economic orientation and social-territorial organization. A sustainable pastoral system would be expected to cope with a few years, but not with decades of drought. Achieving sustainability decreases as rainfall reliability declines, population pressure increases and freedom of movement diminishes.

This paper analyzes resource allocation among pastoralists and suggests strategies for sustainable development in rangelands. For the context of this paper, we define sustainable development as the process of preventing social ecological systems from moving into undesirable trajectories, while achieving sustainable development is the reduction of undesirable ecological systems and increasing desirable systems (Walker, 2003). Holding constant such stochastic losses, each herder is expected to choose the trajectory they want to follow in resource allocation. The premise of static tragedy of the commons model is that each individual chooses a privately optimal use level. However, in the production context facing many herders in dry lands, the ability of an individual to select a herd size is severely limited because stochastic herd loss often limits herders' ability to choose a stocking rate (McPeak, 2000). We argue that choosing the optimal number of livestock to be kept by herders is a critical determinant of the socially optimal number of livestock that can be sustained on a given grazing field. Once the optimal allocation has been attained, the next step is for the herders to adopt strategies that ensure sustainability/resilience of the pastures[4]. In this respect, we define sustainability as a situation where the rate of harvest of biomass by livestock is equal to the regeneration of biomass. However we note that the main issue with resilience management is that it requires knowledge of thresholds, yet it is often difficult to know where exactly the thresholds (such as the optimal herd size) to ensure resilient management are.

The rest of the paper is organized as follows. Section 2 presents a simple model of resource allocation and sustainability of grazing lands. Section 3 discusses the study area and the data. Section 4 presents the empirical results, while section 5 examines the main challenges to sustainable resource management in Kenyan rangelands with particular reference from Kajiado district, and draws policy lessons for sustainable development. Section 6 concludes.

A Model of Resource Allocation and Sustainability in Rangelands

Suppose we assume that our rangeland has only two important species: cattle and vegetation. We further assume that livestock

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3 Sustainable natural resource management refers principally to environmental sustainability. Such a notion of sustainability is however not absolute but related to our capacity to predict change.

4 Resilience is the ability of a system to absorb impact without necessarily changing (Holling, 1973).

yields some benefit to the owner (in terms of milk, meat or other products) or a unit of these products can be sold at an exogenously given price. On the other hand, cattle involve a financial cost to the herder per unit produced (such as capital cost of purchasing cattle, feed, inputs such as drugs and the opportunity cost in terms of other activities forgone). The control variable available to the herder over a given time horizon of the decision problem is the discrete harvest or livestock off take. The herder can then choose the optimal amount of livestock in each period of the discrete control sequence. If he holds too many cattle, the range will be overgrazed (a decline in vegetation), but holding just the right number will ensure a balance between harvest and regeneration of biomass and therefore ensure sustainability of the rangeland. We assume that herders are fully independent in making individual decisions on the herd size to keep and that each herder is assumed to keep what he perceives to be the optimal herd size, holding that of other herders constant.

To explain the resource allocation mechanism, we first focus on the choice decision of the producer to enter or not to enter livestock production, then focus on the optimal herd size that is expected to yield maximum net benefits to the herder. In the first instance, we note that some households are able to enter into livestock production because among other factors, they are able to raise the required initial investment, while some households do not have this option. We can therefore employ the probit framework to analyze the determinants of entering into livestock production. Simultaneously, we can explore the mechanism which determines income for the livestock keepers and non-livestock keepers. We note here that the decision to keep or not to keep livestock will affect the income of the household. We therefore need to take into account sample selection bias that may arise from this decision because the selection of households that keep/do not keep cattle is not random. To do so, we apply the Heckman two-stage estimation procedure based on the probit results for the livestock rearing decision.

The Heckman selection model assumes that there exists an underlying regression relationship of the form

$$y_j = x_j \beta + \mu_{ij} \qquad ...(1)$$

The dependent variable in this regression equation (income/revenue) is not always observed. Rather, the dependent variable for observation j is observed if

$$Z_j\gamma + \mu_{ij} > 0, \qquad ...(2)$$

equation (2) is the selection equation where, $\mu_1 = N(0, delta)$, $\mu_2 = N(0,1)$, $corr(\mu_1, \mu_2) = \rho$

Once the two-step estimates are computed using the Heckman's (1979) procedure, probit estimates of the selection equation are obtained i.e.,

$$Pr(y_j \text{ observed} \mid Z_j) = \varphi(Z_j\gamma)$$

From these estimates, the nonselection hazard (inverse of the Mill's ratio), m_j for each observation j is computed as

$$m_1 = \frac{\varphi(Z_j\, \gamma hat)}{\phi(Z_j\, \gamma hat)}$$

where, ϕ is the normal density. Following Heckman (1979), the two-step parameter estimates of ß are obtained by augmenting the regression equation with the non-selection hazard m so that the selectivity corrected income equation becomes

$$y_j = x_j\beta + m_j\beta + v_i \qquad ...(3)$$

Another issue that we explore using the same mechanism is the optimal herd size conditional on holding livestock. We assume that the total livestock owned by any herder represents the optimal herd size at a given period, all other factors held constant. We hypothesize that the optimal herd size will be influenced by assets such as total land owned, household characteristics and village level characteristics such as availability of water. The main issue that arises from this type of analysis is the identification problem. Application of the Heckman procedure requires the selection of identifying variables that affect the decision to keep livestock, but do not affect income on one hand and herd size on the other. We use property incomes and transfers (remittances) to identify our models. We argue that these variables affect the decision to keep livestock, but it is not clear why they would affect income or herd size.

Study Site and Data

This paper uses data collected from Kajiado district, located on the southern part of the Rift Valley province of Kenya covering an area of 21,105 square kilometers. The district spans four agro-ecological zones: a semi-humid climate that supports mixed agriculture, an arable semi-arid climate and an arid climate, favorable mainly for ranching and pastoral activities[5].

The data for the study were collected from a cross section of households in Kajiado district over the period March 1999 to May 2000 in three phases. The first phase corresponded with the long rains (March-May 1999), the second phase with the short rains (October-December 1999), and the third phase with the long rains (March-May 2000). The National Sample Survey and Evaluation Programme of the Central Bureau of Statistics, Ministry of Planning and National Development (Republic of Kenya, 1996) was used as the sampling frame for the field survey. The analysis is based on a sub-sample of 1600 herders. A detailed questionnaire was used to collect the requisite data. The questionnaire was designed to collect information regarding economic and demographic characteristics of sampled households, on farm yields and soil conservation practices, and land use rights, among other covariates of interest.

The secondary data for the study concerning the quantity of biomass at the village level was obtained from the Department of Resource Surveys and Remote Sensing (DRSRS), Ministry of Natural Resources, Environment and Wildlife. These data are derived from satellite images and vegetation indices collected by the National Oceanic and Atmospheric Administration, and translated

[5] The classification of these agro-ecological zones is based on differences in soil quality, rainfall variability, altitude and vegetation. Land in the district spans between semi-humid climate (1.2%), arable semi-humid/semi arid (6.5%) and arid climate (92.3%). We created dummies for the administrative divisions to capture agro-ecological zones as our sample clusters were scattered through out the entire district and thus fell under different agro-ecological zones.

into biomass in kilograms per acre of land in village clusters by the DRSRS. We used the data in the same form that we received them from the DRSRS.

A summary of the key variables used in this paper is presented in Table 1. A quick view indicates that about 73% of all herders in the sample held land under private property arrangements, compared to only 27 holding land under common property (group ranches) and less than 1% under tenancy arrangements. Another highlight from the data is the level of inequality as portrayed by large standard deviations of the assets variables, namely land and livestock holdings.

Table 1. Definition and measurement of variables, N=1600

Variable	Mean	Std. Dev.
Tenures security factors		
Right to sell (hence own plot) (1 = yes, 0 = no)	0.73	0.45
Land belongs to scheme (group ranch) (1 = yes, 0 = no)	0.27	0.40
Tenant (1 = yes, 0 = no)	0.07	0.25
Assets		
Total land owned (acres)	98.08	145.24
Rent incomes (Kshs'000)	11.26	37.53
Transfers incomes (Kshs'000)	2.14	10.01
Total livestock units owned	35.00	93.76
Number of small ruminants (sheep and goats) owned	59.78	148.60
Household Characteristics		
Household size	8.42	5.45
Age of household head	35.16	13.22
Sex (1 = male, 0 = female)	0.49	0.50
Marital status (1 = married, 0 = not married)	0.69	0.46
Primary school education (1 = yes, 0 = no)	0.31	0.46
Secondary school education (1 = yes, 0 = no)	0.17	0.38
Post-secondary education (1 = yes, 0 = no)	0.03	0.18
Herder migrates with livestock (1 = yes, 0 = no)	0.56	0.50
Household also cultivates crops (1 = yes, 0 = no)	0.73	0.44
Market factors		
Price per head of cattle (Kshs)	1417.00	542.00
Price per sheep/goat (Kshs)	7829.00	3546.00
Distance to market (kms)	11.73	9.65
Distance to source of water (kms)	3.45	4.58
Agro-ecological zones (Division Household is Located)		
Loitoktok (1 = yes, 0 = no)	0.30	0.46
Mashuru (1 = yes, 0 = no)	0.13	0.33
Ngong (1 = yes, 0 = no)	0.28	0.45
Central (1 = yes, 0 = no)	0.10	0.30
Magadi (1 = yes, 0 = no)	0.08	0.28
Namanga (1 = yes, 0 = no)	0.11	0.31

The probit regression framework is employed to determine the factors influencing the decision to hold livestock, based on the full sample of households in the sample. The OLS regression framework is used to explain the optimal incomes and herd size based on the sample of households that participated in livestock keeping. The probit and OLS frameworks are linked through the Heckman selection model to control for selectivity bias. We discuss the results below.

Determinants of Decision to Hold Livestock

The paper sought to explain why some households in rangelands hold livestock while others do not. The regression results from the Heckman selection model are presented in Table 2. The first three rows suggest that tenure security is an important determinant of the decision to hold livestock. In particular, households who have the right to sell land (and therefore to bequeath and lease out) are more likely to keep livestock than those who do not have this right. The same case is observed for households holding land under common property resources. On the contrary, households holding land under tenancy arrangements are less likely to keep livestock, due to insecurity of tenure.

The results further show that as would be expected households with larger tracts of land are more likely to keep livestock than their counterparts with less land. Other factors which are observed to have a positive impact on the probability of holding livestock include household size, which can also be interpreted as a proxy for family labor; marital status, prices for small stocks (ruminants) and the region where a household is located. The location of the household has the expected positive impact, implying that households located in less arable regions are more likely to keep livestock relative to those in arable regions. Distance to source of water and whether a household cultivates crops or not have the unexpected positive impacts, implying that they may not be important determinants of the decision to hold livestock.

Age and gender of the household head do not seem to be important determinants of the likelihood of keeping livestock. Education seems to reduce the likelihood of holding livestock, though only the primary education dummy has a significant effect. The implication here is that such households may have alternative income earning opportunities to livestock production. Household with higher access to transfers are less likely to keep livestock than their counterparts who receive less transfers. This result implies that other sources of income are likely to reduce reliance on livestock and therefore act as a disincentive to hold livestock; more so where households have target income levels. So long as the threshold is satisfied, such households are unlikely to devote more resources into other activities including stocking.

Determinants of Optimal Incomes from Holding Livestock

Table 3 presents the results for incomes accruing to herders, once they enter livestock production. The income so obtained is interpreted as the optimal level of income, holding other factors constant and assuming

Table 2. Determinants of participation in livestock production (Heckman Selection Model)

Variable	Coefficient	Std. error	Z - value
Right to sell land (1 = yes, 0 = no)	0.390*	0.107	3.65
Land belongs to scheme (1 = yes, 0 = no)	0.853*	0.181	4.72
Tenant (1 = yes, 0 = no)	-0.835*	0.165	-5.07
Log total land owned (acres)	0.233*	0.028	8.37
Log household size	0.579*	0.092	6.3
Log age of household member	-0.237***	0.139	-1.71
Sex (1 = male, 0 = female)	-0.030	0.088	-0.34
Marital status (1 = married, 0 = not married)	0.291*	0.104	2.8
Primary school education (1 = yes, 0 = no)	-0.288**	0.127	-2.27
Secondary school education (1 = yes, 0 = no)	-0.102	0.148	-0.69
Post-secondary education (1 = yes, 0 = no)	-0.051	0.233	-0.22
Log distance to markets	-0.161*	0.059	-2.73
Log distance to source of water	0.208*	0.054	3.82
Log price per sheep/goat	0.280**	0.140	2
Log price per cow	0.007	0.114	0.07
Herder also cultivates crops (1 = yes, 0 = no)	0.603*	0.137	4.4
Log transfers incomes	-0.039*	0.013	-3
Log rent incomes	-0.006	0.024	-0.26
Magadi (1 = yes, 0 = no)	0.444**	0.239	1.86
Mashuru (1 = yes, 0 = no)	0.269	0.175	1.54
Ngong (1 = yes, 0 = no)	0.984*	0.142	6.94
Central (1 = yes, 0 = no)	1.140*	0.276	4.12
Namanga (1 = yes, 0 = no)	0.718*	0.222	3.23
Constant	-3.171	1.141	-2.78
Number of observations (censored)			367

***,**,* Significant at 1%, 5% and 10%, respectively.

full efficiency of the producer. The results indicate that households who have the strongest rights to land (sell, bequeath or lease) report higher income from livestock than their counterparts with less security of tenure. Household size, level of education, availability of biomass and technology have the expected positive impacts on income. Like for livestock ownership, we do not observe age, gender and marital status to be important determinants of optimal income.

Livestock prices have the unexpected negative impacts, implying that holding quantity of livestock constant, prices may not be important determinants of income. The same result is observed for migration in search of pasture and water. Except for one region, all other regions are observed to report less livestock income than the reference region. The lambda term has an insignificant coefficient implying that there is no selectivity issue in the decision to hold livestock and therefore, we expect

Table 3. Selectivity corrected OLS results for determinants of optimal incomes

Variable	Coefficient	Std. error	Z - value
Right to sell land (1 = yes, 0 = no)	0.519*	0.181	2.87
Land belongs to scheme (1 = yes, 0 = no)	-0.728*	0.238	-3.06
Tenant (1 = yes, 0 = no)	-0.114	0.514	-0.22
Log total land owned (acres)	-0.173*	0.050	-3.47
Log hired labor inputs	0.044*	0.016	2.8
Log household size	0.572*	0.141	4.05
Log age of household member	0.001	0.198	0
Sex (1 = male, 0 = female)	-0.150	0.125	-1.19
Marital status (1 = married, 0 = not married)	0.072	0.169	0.43
Primary school education (1 = yes, 0 = no)	0.471*	0.169	2.79
Secondary school education (1 = yes, 0 = no)	0.980*	0.209	4.7
Post secondary education (1 = yes, 0 = no)	1.369*	0.363	3.77
Log distance to markets	-0.033	0.084	-0.4
Log distance to source of water	0.102	0.085	1.19
Log biomass	2.719*	0.313	8.69
Log price per sheep/goat	-0.649*	0.225	-2.88
Log price per cow	-0.624*	0.155	-4.02
Herder migrates with livestock	-0.175	0.154	-1.13
Magadi (1 = yes, 0 = no)	-0.926*	0.299	-3.1
Mashuru (1 = yes, 0 = no)	0.199	0.243	0.82
Ngong (1 = yes, 0 = no)	-2.489*	0.302	-8.24
Central (1 = yes, 0 = no)	-0.999*	0.266	-3.75
Namanga (1 = yes, 0 = no)	-1.212*	0.322	-3.76
Lambda (1 = yes, 0 = no)	-0.202	0.498	-0.41
Constant	-2.403	3.287	-0.73
Number of observations (uncensored)			1235
Wald X2(43) = 942.92			Prob >X2 = 0.0000

***, **, * Significant at 1%, 5% and 10%, respectively.

to draw similar conclusion for results based on single equation probit for livestock holding and OLS regression for optimal income from livestock production[6].

Determinants of Optimal Herd Size

The estimation results for the optimal herd size derived from the Heckman selection model are presented in Table 3. The results indicate that as expected, tenure security is an important determinant of optimal livestock holding, as implied by the significant coefficients for households with full ownership rights and those holding land under common property arrangements. Tenants are less likely to hold the optimal

[6] This implies that there are no unobserved important characteristics possessed by livestock owners and not by non-owners.

number of livestock due to uncertainty of tenure. Like for the optimal income from livestock holding model, larger land holdings, availability of labor (both hired and family labor) and marital status are also important factors for optimal livestock holding. Herders who migrate with livestock in search of pasture and water are observed to keep more livestock than their counterparts who do not migrate. Such herders are less constrained in terms of availability of pasture and can therefore keep more livestock. Relative to more arable regions, the agro-ecological zone in which a household is located is also an important determinant of optimal livestock holding.

Distance to markets, availability of water and biomass turn out to have the unexpected signs, which implies that they may not be critical factors for optimal livestock holding. The unexpected sign of the coefficient for biomass is hard to interpret. The impact of markets confirm the observation that livestock production in the district is not market responsive because livestock is held as a sign of wealth and status and the herders would be less willing to sell their livestock the higher the prices. This is confirmed by the results for livestock prices, for which we do not uncover any important impact. The results for water could be explained by two facts: one more than 90% of the livestock in the district is traditional herds, which can survive with less water than modern breeds; two, in cases of severe drought, the herders move their animals in search of pasture and water, rather than dispose off their herds. Age and education of the household head are observed to have a negative impact on optimal livestock holding. These results implying that a herder is likely to reduce the herd size at old age and that more educated household heads are likely to keep less livestock than their more educated counterparts, probably due to alternative income earning opportunities. However, only the primary schooling dummy has a significant coefficient. As observed for the results for participation in livestock holding, the results for the agro-ecological zones confirm that herders located in arid areas are likely to keep more livestock than those located in more arable areas.

The selectivity term turns out to be highly significant indicating the importance of self-selection of households in participation in livestock production and in determining the optimal stocking rates. This conclusion is supported by the Wald Chi^2 test for the independence of the equations presented on the last two rows of Table 4. Using the Heckman approach therefore yields unbiased estimates of the coefficients because the variables that affect the decision to hold livestock also affect optimal stocking levels. The coefficient for rent incomes in Table 3 is insignificant implying that this variable is neither an important determinant of the decision to keep livestock, nor a good instrument for identifying optimal livestock ownership. However, we conclude that transfers turn to be a significant instrument for identifying the optimal livestock holding. The argument is that though low levels of remittance affect the decision to keep livestock; it is not clear why they should influence the optimal livestock holding, once a household decides to hold livestock[7]. This result also supports expectations that higher

[7] Though transfer incomes seem a good instrument, we could argue that identification can also be based on distributional assumptions (See for instance Imai, 2003).

Table 4. Selectivity corrected OLS results for determinants of optimal herd size

Variable	Coefficient	Std. Error	Z - value
Right to sell land (1 = yes, 0 = no)	0.479*	0.095	5.04
Land belongs to scheme (1 = yes, 0 = no)	0.278**	0.128	2.18
Tenant (1 = yes, 0 = no)	-1.402*	0.237	-5.92
Log total land owned (acres)	0.149*	0.026	5.72
Log hired labor inputs	0.051*	0.008	6.59
Log household size	0.898*	0.076	11.89
Log age of household member	-0.291*	0.106	-2.75
Sex (1 = male, 0 = female)	0.004	0.067	0.06
Marital status (1 = married, 0 = not married)	0.471*	0.089	5.31
Primary school education (1 = yes, 0 = no)	-0.397*	0.091	-4.37
Secondary school education (1 = yes, 0 = no)	-0.041	0.111	-0.37
Post-secondary education (1 = yes, 0 = no)	0.117	0.191	0.61
Log distance to markets	0.073	0.045	1.64
Log distance to source of water	0.288*	0.045	6.4
Log biomass	-0.284**	0.155	-1.84
Log price per sheep/goat	0.167	0.118	1.42
Log price per cow	0.044	0.084	0.53
Herder migrates with livestock	0.736*	0.074	9.98
Magadi (1 = yes, 0 = no)	1.056*	0.159	6.62
Mashuru (1 = yes, 0 = no)	0.677*	0.129	5.26
Ngong (1 = yes, 0 = no)	0.993*	0.151	6.56
Central (1 = yes, 0 = no)	0.420*	0.142	2.96
Namanga (1 = yes, 0 = no)	1.219*	0.166	7.36
Lambda (1 = yes, 0 = no)	1.157*	0.241	4.8
Constant	-0.654	1.642	-0.4
Number of observations (uncensored)			1235
Wald X2(43) = 942.92			Prob >X2 = 0.0000

***, **, * Significant at 1%, 5% and 10%, respectively.

resource endowments give a higher probability of being able to enter livestock production (Imai, 2003).

Sustainable Rangeland Management: A Case Study of Kajiado District

Challenges

Population pressure and concomitant factors: Population pressure is perhaps one of the most important forces inhibiting sustainability in rangelands and thus a real challenge to sustainable development. Available evidence seems to point to the fact that population pressure cripples the ability of rangelands to support future generations (World Bank, 1997). The main indicator of population pressure is the stock wealth. The proportion of families whose stock wealth is inadequate in numbers and composition for family security is an indicator of population pressure and unsustainability. However, there is always a certain threshold of stock wealth beyond which a given area cannot sustain, given the carrying capacity of the land. In the study district, there is evidence of stock pressure given the agro-climatic conditions. In spite of relatively low human population (less than 25 people per square kilometre), and high average stock holding per household (35 heads of cattle per household), the carrying capacity of land is very low at 0.82 cattle per acre of land in the study area (Kabubo-Mariara, 2003b).

Environmental indicators can also be used as evidence of population pressure. Desertification, loss of top soil and biodiversity, logging, forest fires as well as modification of habitat for domestic use and the corresponding impact on the natural habitat all have negative implications for sustainable development (Giulio, 2003). In Kajiado district and other arid and semi-arid pastoral areas, the main environmental indicator of population pressure is browse giving way to useless weed species and declining stock wealth due to overgrazing (World Bank, 1997; Kabubo-Mariara, 2003b).

Cultural barriers, while an obstacle to sustainable development on their own (de Leo, 2003), in many ways could aggravate population pressure. In many instances, the range management practices adopted by pastoralists depend on their culture. In most pastoral communities, cattle are regarded as wealth and play an important role in social functions such as marriage exchanges and bride price payment. In other instances, where markets are underdeveloped, a lot of cattle are always held for insurance purposes to ensure that the herder does not lose all livestock to drought (Dasgupta and Mäler, 1995). This often leads to unsustainable livestock holdings in many pastoral communities. In our sample, we observed that the *Maasai* are very reluctant to sell their cattle even in periods of severe drought due to the "wealth effect" of holding more livestock.

Institutional framework

The role of institutional arrangements in sustainable development cannot be overemphasized. While decentralization is important for enhancing local participation and resource management at the grass root level, the state has an important role to play in providing the necessary institutional framework for sustainable development. Two important aspects of supporting institutional framework for sustainable rangeland management and development are property rights and infrastructure.

Property right institutions

The nature of rights in property constitutes a significant part of the institutional structure of any community. It defines how people relate to resources and use them (Chopra and Gulati, 2001). Most rangeland areas have ambiguous property status; such that there is a difference between access and tenure, yet the property status of grazing lands vary among societies, localities and seasons.

In the district under consideration, we observe a breakdown in collective action and a movement towards private property which are legally sanctioned[8]. Though available evidence indicates that privatization of common property rights is necessary to reduce efficiency in grazing lands, our field observations indicated that this is not always the case. In most group ranches, there is evidence of overgrazing thanks to the controls imposed by group elders before members could be allowed to move their herds to other fields. Our analysis further showed that herders holding land under private property reported higher productivity from total aggregate crop and livestock production than their counterparts holding land under common property (Kabubo-Mariara, 2003b). Our argument here is that well specified property right institutions could create an enabling environment for sustainable development even in grazing areas, while on the other hand; good management of common property resources and the incentives created by the system (and most important ability to achieve and sustain collective action) could create room for optimal resource allocation and sustainability. This supports increasing evidence which shows that privatization of resources form the basis for the evolution and proper management of common property resources (Kebede, 2002; Chopra and Gulati, 2001)

Infrastructure

One major challenge in rangelands is marginalization in terms of infrastructural development. Most pastoral areas are inaccessible and lack basic facilities such as water, all weather roads, health services and markets. Water is very crucial for any livestock system, yet households in our sample were found to travel long distance in search of water, while available water sources were highly polluted and unprotected due to the high numbers of household and livestock that depend on them. The mean distance to source of water in our sample was found to be about 3.5 km with a maximum distance of 20 km (Table 1). 42% of all households travelled more than 3.5 km everyday in search of water. Provision of water is therefore one major challenge that needs to be urgently addressed in the district if sustainability is to be achieved. Markets are much more inaccessible than water, with a mean distance of 12 km and a maximum distance of 40 km. Furthermore, 39% of all households travelled more than 12 km to reach the market. The consequence of this inaccessibility is that households do not enjoy benefits of markets and are often left out in market transaction (Ensminger, 1992; Kabubo-Mariara, 2005). Health facilities are not only inaccessible, but also poorly equipped, forcing most pastoralists to travel long distances in search of medical assistances. This probably explains very high mortality rates in the district (Kishel *et al.*, 1999). In addition to infrastructure, knowledge and information flow are also essential for sustainable development. Yet for many pastoralists, information flow and low literacy rates are major problems, which tend to shut out herders from the outside world (Kabubo-Mariara, 2005).

Poverty

Poverty is one of the greatest barriers to sustainable development. According to Conrad (2002), people on the edge of starvation are not in a position to reduce

8 In Kenya, common property resources are held under group ranches, and the law allows all group land to be granted a freehold title. The group then has exclusive rights to make decisions on the use and disposal of the resources.

harvest today or to invest in stock tomorrow. Increasing evidence indicates that poverty is not only an effect, but also a cause of unsustainable resource use through environmental degradation. Evidence from Kenya shows that pastoralists are among the poor and vulnerable groups, which limits their prospects of managing their resources towards sustainability. In our sample, the most important determinants of poverty among herders were found to be property right regimes and investment in land improvements (Kabubo-Mariara 2003a), implying that policies addressing these issues would have important implications for sustainability.

Policies for sustainable rangeland management

In this section, we briefly examine the alternative policies that would ensure sustainability in resource allocation in rangelands, based on the barriers identified above. However, we caution that the challenges identified above could be intertwined in a complex manner, such that a multi-dimensional approach to sustainable rangeland management and development may be more feasible than just dwelling on individual barriers.

The first policy intervention should focus on population issues. In Kajiado, livestock population rather than human population is the main obstacle to sustainable development. There is therefore need to invest in public awareness campaigns to educate the Maasai on the importance of keeping smaller herds. The awareness campaigns need to focus on issues of herd productivity in terms of stock flows rather than physical stock. Dissemination of information on the outbreak, spread and treatment of livestock diseases is another important aspect that could improve animal husbandry and ensure sustainability. Research and development into new range management practices and biomass growth is essential. In particular, research into different types of drought resistant vegetation would have important implications for sustainable development. In the long-term, formal education would be vital as it would increase awareness as well as broaden alternative income earning opportunities (Kabubo-Mariara 2005)

Institutional support is a necessary condition for sustainable development in rangelands. Well specified property rights could enable herders to move towards better management of their resources and creation of common property institutions that support natural resource management (Kebede, 2002; Chopra and Gulati, 2001). Mechanisms for ensuring collective action and preservation of norms under common property resources would ensure sustainability of common property resource use and probably avert the "tragedy of the commons" (Hardin 1968). Provision of water is an urgent priority in rangelands. Community participation could be enhanced with seed funding to sink boreholes in more arid areas or to access piped water in less arid areas. Market development and provision of basic infrastructure and social services are urgent interventions for sustainable development.

Poverty alleviation efforts could minimize the quest for satisfaction of short-term needs while jeopardizing future productivity and sustainability. In this regard, it is crucial for herders to be encouraged to take up non-herding activities to complement their stocks. This would increase incomes and consumption and therefore reduce the level of poverty. Important strategies could include crop cultivation and non-farm activities such as trade (in livestock, livestock products and non-livestock products) and bead making among other activities. These activities are livelihood diversification strategies which would increase the welfare of herders and therefore encourage conservation of biodiversity and optimal resource allocation. Species diversity could not only help to take optimal advantage of the heterogeneous nature of ecosystems but also help to manage risks associated with drought (Kabubo-Mariara, 2005a, 2005b).

Conclusions

This paper explores resource allocation decisions in Kenyan rangelands, with specific reference to Kajiado district. We analyze choice decision of the producer to enter or not to enter livestock production, and the optimal herd size that is expected to yield maximum benefits to the herder. Choice of optimal herd size is expected to ensure sustainable management and development of the rangeland. We apply the Heckman two-stage estimation procedure to correct for selectivity bias in the livestock production, optimal income and optimal herd size process. The results show that tenure security, assets ownership and location of the household are important determinants of the decision to hold livestock and the resulting optimal stocking rates and incomes. We find no evidence of selectivity bias in the decision to hold livestock implying that characteristics of household that hold livestock do not differ with characteristics of household who do not keep livestock. However, we find evidence of self-selection in the determination of participation in livestock production and the optimal stocking rates.

The paper also attempts to conceptualize sustainable rangeland management and development drawing from available literature and data collected from the district. The analysis shows that the main challenges to sustainable development in rangelands include population pressure and related factors (environmental fragility and cultural barriers), lack of supporting institutional framework and poverty. We recommend policies that would overcome these barriers in order to pave way for sustainable development. We however caution that sustainability may require a multidimensional approach in addressing the identified barriers.

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